# AN ASSESSMENT OF
# THE POTENTIAL OF SOLAR ENERGY
# IN MANITOBA

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# AN ASSESSMENT OF THE POTENTIAL OF SOLAR ENERGY IN MANITOBA

## EXECUTIVE SUMMARY

This study was undertaken to assess the potential of active and passive solar energy applications within the province of Manitoba. Comparisons were made between various solar energy systems and conventional systems which use natural gas, electricity, or oil as their energy source. Comparisons were also made with known or potential energy conservation alternatives.

With few exceptions, it was found that active solar energy is not presently a viable alternative in Manitoba due to a combination of high system costs and low system energy production. Numerous energy conservation practices and technologies were also identified which proved to be significantly more cost effective that active solar energy. Some possible exceptions to this include certain applications of ventilation air preheating, commercial and industrial service water heating, swimming pool heating and (potentially) photovoltaic generation of electricity. Although dependent upon the results of ongoing research and development, these conclusions are not expected to change within the immediate future.

The potential of passive solar energy was found to be considerably brighter, especially for single family housing, multifamily housing and commercial building applications. In these cases, solar energy was found to often be capable of providing an economic source of heat and light in new construction. Warehouse and greenhouse applications were found to generally be less cost effective.

# CHAPTER 1

## INTRODUCTION

### 1.1 ASSESSING THE POTENTIAL

Each year enough solar radiation falls on Manitoba to meet the province's energy needs for approximately 10,000 years. Some of this energy is already harnessed by our agricultural industries, our hydroelectric system, and by various other applications. Lately, however, the possibility of using the sun to contribute directly to meeting some of our energy requirements has received increased attention.

This report was undertaken to assess and report on the potential of direct applications of solar energy which exist within the province of Manitoba. Direct applications were defined as active and passive solar energy systems which could supply thermal, photoelectric or lighting energy. Hydraulic, wind, and biomass systems were excluded from the terms of reference.

The primary assessment tool used in the analysis was economics, for three reasons. First, the economics of an investment are relatively easy to determine and compare, assuming the method of analysis is applicable to the situation under study. Second, most consumers, on an individual or corporate level, are primarily concerned with the financial aspects of an investment. While perhaps considering other factors such as environmental and social issues, they are usually reluctant to be seriously swayed by these factors because they do not see themselves as major contributors to the problem.

The final reason for relying upon economics is the relationship between solar energy and energy conservation. Both possess virtually identical environmental and social advantages and disadvantages. In essence, the noneconomic considerations cancel out, leaving solar and conservation in a class by themselves, distinct from conventional energy sources. While this report was not specifically concerned with energy conservation, any rational investor or consumer would obviously consider it along with solar energy. Therefore, it was decided that any attempt to evaluate a solar technology must not only compare it to conventional fuels, but also to any applicable energy conservation alternatives. Such was the rationale used in this report.

### 1.2 ECONOMIC ASSESSMENT

Each solar application was evaluated from two perspectives. First, wherever possible, Simple Payback Periods (SPP) for the proposed solar application were determined and a Life Cycle Cost (LCC) analysis was performed to allow comparison with conventional energy sources. Any appropriate environmental or social considerations were used to temper conclusions drawn from these calculations. Second, direct economic comparisons were made between the solar technologies and any applicable energy conservation alternatives (the other factors cancelling out). This dual approach provided a realistic view of the potential of each solar application.

The Simple Payback Period (SPP) was defined as the total investment cost of the solar energy system divided by the direct, pretax benefits derived from it in the first year of operation. Unfortunately, this procedure does not accurately reflect future energy costs or interest rates. However, it is easily understood and useful for comparison purposes.

Life Cycle Cost (LCC) analysis attempts to consider these future conditions and account for the effects of increasing savings over the life of a solar energy system due to rising replacement fuel costs. The accuracy of LCC analysis is, of course, limited by the uncertainty of predicting future conditions.

A major problem in the assessment was determining what economic return is required to see a product or technology utilized. For example, what payback period would consumers demand before installing a solar water heater? A recent American survey of 4,000 people concluded that most view solar heating as very attractive. Yet 50% would demand a five year payback to consider it seriously. To increase this to 80% would require a two year payback (Ref. 1). The view of most Canadians would likely be similar. In the business community, most firms will only proceed with investments if the payback period does not exceed three to four years, although exact definitions of "payback period" may vary. Also, few firms analyze investments of this size using LCC - a disadvantage for the capital intensive solar technologies. Therefore, Simple Payback Periods were generally used in this report to make short-term predictions and Life Cycle Costing for long-term forecasts.

The form of LCC analysis used herein employs the concept of Series Present Worth Factors (SPWF). This determines how large an investment can be made per dollar invested in a solar technology. For example, a SPWF of 20 would stipulate that a maximum expenditure of $20 could be justified if it produced a saving of $1 in the first year.

By varying the assumed future conditions, wide variations in the SPWF can result. This invariably creates debate over the realism of the original assumptions and often obscures the real issues. Therefore, in an attempt to circumvent this problem a singular value of the SPWF was used in all LCC calculations. Obviously this is likely to be inexact but it was considered a reasonable first approximation, considering the volatile nature of energy costs and interest rates. Therefore the results of all LCC analyses were treated as having potentially large margins of error. Instead of relying upon the absolute values of the calculations, attention was focused on the general trends of the results. Conclusions were then drawn from these trends.

Most LCC analyses of solar energy systems use a SPWF of 15 to 25. A figure of 20 was adopted for this report. This can be viewed as an extreme value favoring solar energy developments, even though most commercial investors would consider 20 excessively high. It would be produced by a wide range of probable interest rate, energy escalation rate, and length of term combinations. A set of typical values that would result in an SPWF of 20 is an interest rate equal to the energy escalation rate with a length of term of 20 years.

Other factors such as taxation and marginal costing also enter the picture. Commercial installations would require consideration of the firm's tax situation and the allowable depreciation rate. Marginal costs reflect the fact that replacement costs of energy may be considerably above the average cost.

In this report these factors have been used to qualitatively adjust conclusions drawn from the SPP and LCC analyses, and the comparisons with energy conservation.

## 1.3 TECHNOLOGY REVIEWED

There is always a temptation to speculate upon and eventually plan for major "breakthroughs" when evaluating developing technologies. Unfortunately, this optimism must be tempered with a recognition of the present technology and economic conditions. Therefore, this report considered only existing or probable technologies (defined as those which are likely to reach the marketplace using existing concepts and the normal evolutionary design process). For example, the current cost of a solar domestic hot water system is approximately $2,800 and some industry officials foresee a price of $2,500 within a few years. One could argue that major breakthroughs in design and construction could lower this to (say) $1,000. However, if such a major development is possible, its form is not yet recognizable. Thus a figure of $2,800 or $2,500 would be appropriate for analysis. While some may view this as a pessimistic approach, it should be remembered that if such a breakthrough were to occur, there would be little difficulty adapting to it.

It should be noted that numerous solar energy devices, systems and design approaches have been considered and investigated by researchers over the years. A detailed analysis of each would be outside the scope of this report. Those discussed herein were regarded as the most appropriate for use in Manitoba.

## 1.4 BASIC THEORY OF SOLAR ENERGY UTILIZATION

The sun's energy is produced by thermonuclear fusion and reaches the earth in the form of high frequency electromagnetic radiation. At the outside of the earth's atmosphere, the solar intensity averages 1.35 $kW/m^2$ (429 $Btu/ft^2$-hr), this quantity being known as the solar constant. However, due to atmospheric scattering and absorption, only a portion of this radiation actually reaches the earth's surface. Here, it may be absorbed or reflected back into space.

The solar radiation which reaches the surface of the earth in a straight line from the sun is known as direct or beam radiation, while that which is scattered while passing through the atmosphere is termed diffuse radiation. On a cloudy day virtually all the solar radiation reaching the earth's surface will be diffuse.

Knowing the value of the solar constant is, by itself, of little value for solar energy applications mounted on the earth's surface. The solar radiation reaching a given spot on the surface depends upon

the geographic location of the site, the time of year, the time of day, and of course, the weather. While radiation levels on a particular spot at a specific time are difficult to estimate, long-term monthly or yearly averages can be predicted with accuracy. These averages have been determined for most parts of Canada. Figure 1.1 maps the average annual radiation striking a horizontal surface across Manitoba. As expected, the southern portions of the province receive the maximum levels of solar radiation.

By tilting a surface towards the sun, the amount of radiation striking it can be significantly increased. A considerable effort has been expended by researchers to determine the solar radiation which would strike surfaces facing in various directions, and at various tilt angles. It has been found, for example, that to maximize the radiation striking a fixed surface over the course of the year, the surface should face due south and be tilted at an angle from the horizontal equal to the latitude of the site (i.e. an angle of 50° for Winnipeg). To maximize the solar radiation striking a surface over the course of the heating season (October to April), the surface should also face south but be tilted at an angle equal to the latitudes plus 15° (i.e. 65° for Winnipeg). Fortunately, small variations in the direction and tilt angle can be tolerated without major reductions in the incident radiation. Figure 1.2 plots the average monthly radiation a) on a horizontal surface, b) at the optimum angle for year-round collection, and c) on a vertical surface, for Winnipeg and Churchill. The tilted surfaces face south.

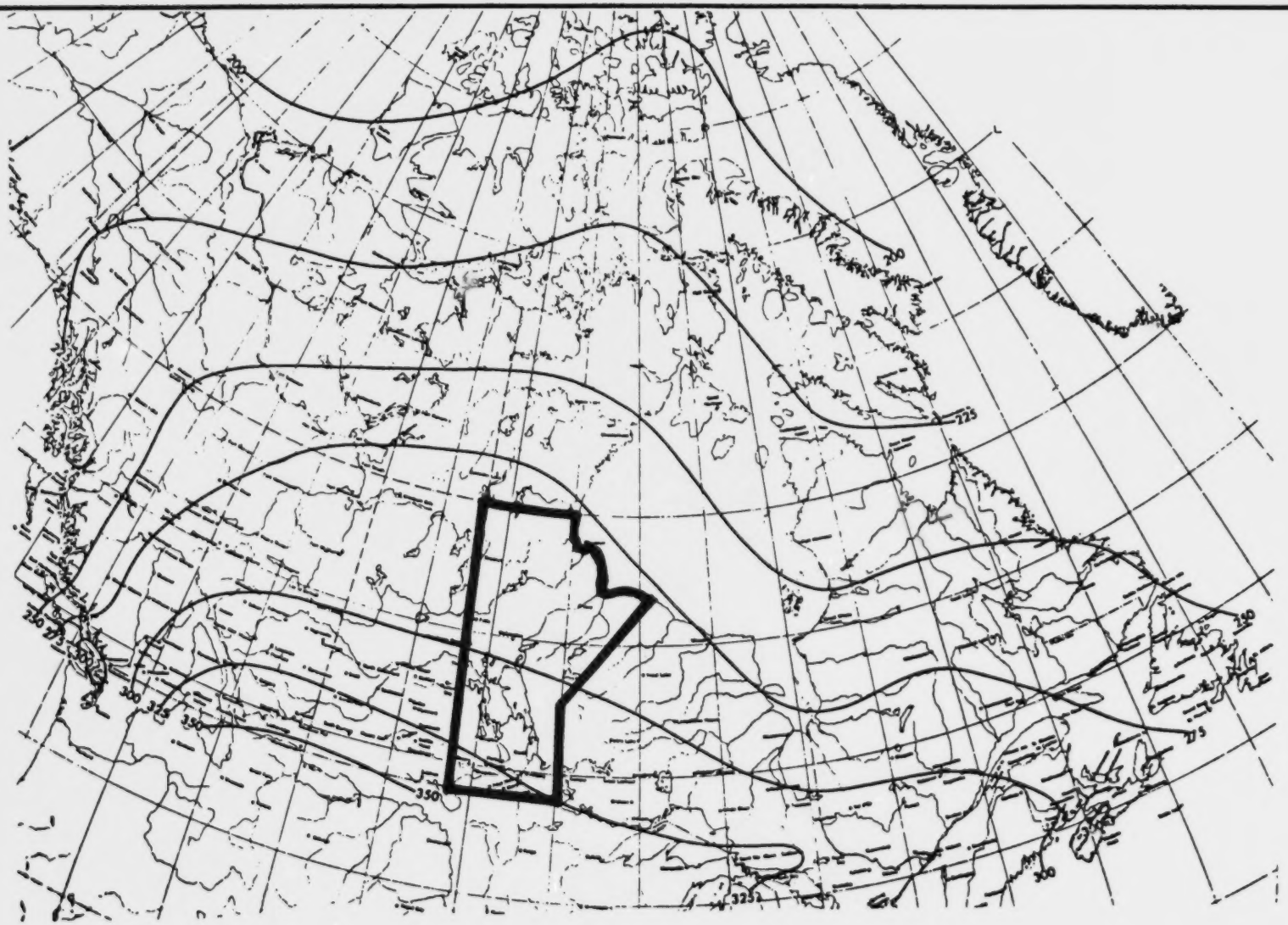
Solar energy systems attempt to utilize this incident radiation for some useful purpose such as heating, cooling, lighting, or the production of electricity (photovoltaics). Most of the efforts to date have been directed at solar heating systems, although interest in photovoltaics has been growing.

Most active solar energy systems being installed in Canada today employ the flat-plate collector as their main component. This device usually consists of a black-painted metal absorber surface covered by one or two layers of glazing. Incoming solar radiation passes largely unimpeded through the glazing and is converted into heat when it strikes the absorber surface. A liquid heat transfer fluid or air circulates under, through, or over the absorber to remove the collected energy. Back and side insulation around the collector minimizes heat loss to the atmosphere.

Current collector designs can operate with efficiencies of 30% to 60% - that is, 30% to 60% of all the radiation striking the outer surface of the collector is eventually converted into useful heat.

Passive solar energy systems use vertical, or sometimes tilted, glazed surfaces, as the principal energy collection mechanisms.

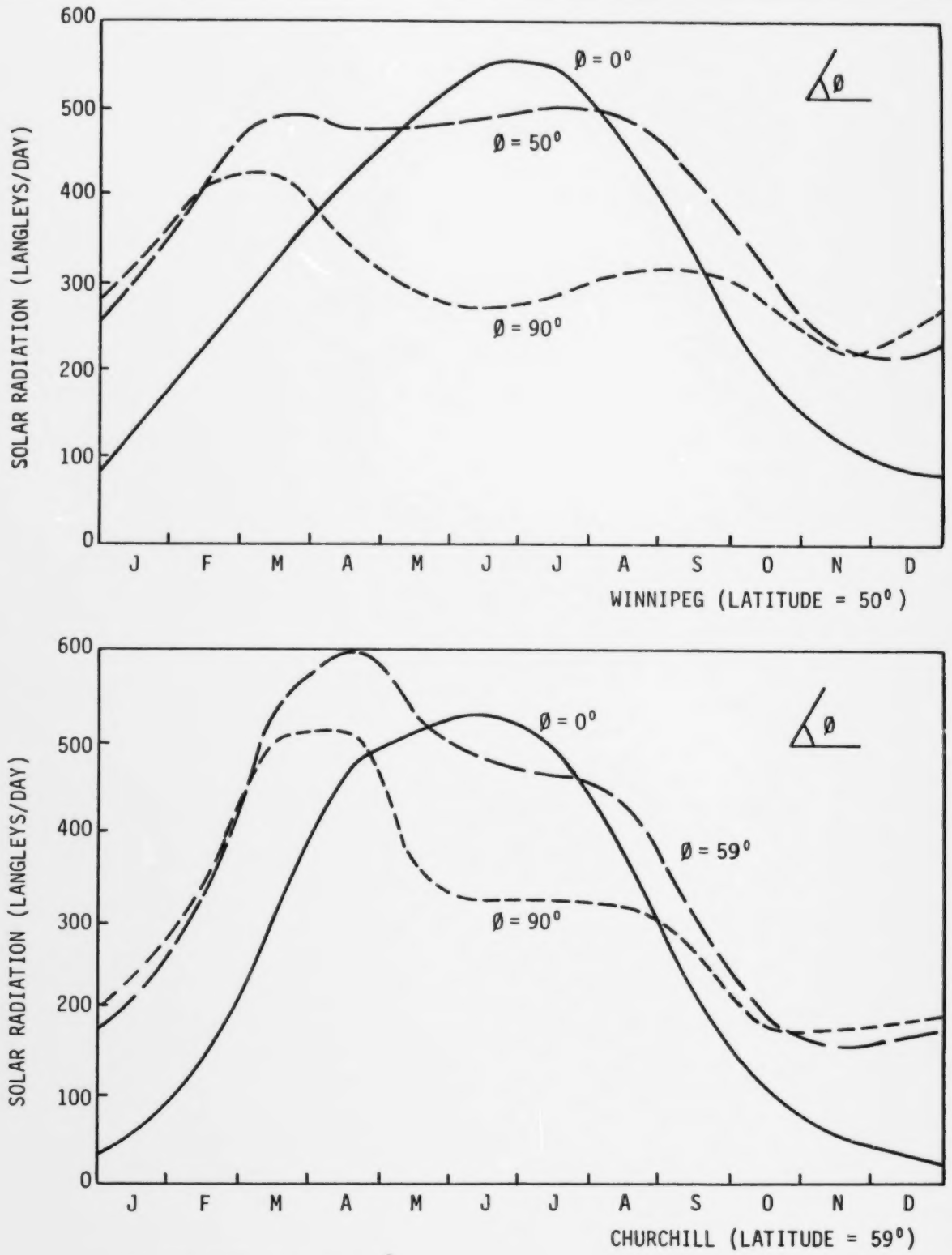
Another factor worthy of consideration is the legal aspect or so-called right-to-light question. It is unclear, especially in the eyes of the building industry, whether a structure or collector array has a right to an unshaded access to the sun, and how any rights can be protected.




1 LANGLEY=3.682 BTU/ft$^2$

MEAN DAILY SOLAR RADIATION
IN LANGLEYS FOR THE YEAR

FIGURE 1.1




1 LANGLEY=3.682 BTU/ft$^2$

MEAN MONTHLY VALUES OF DAILY SOLAR RADIATION ON SOUTH-FACING SURFACES

FIGURE 1.2

All economic solar energy systems, active or passive, have to maximize energy collection and production, attain a reasonable life expectancy, provide reliable operation and still provide energy at competitive prices.

## REFERENCES

(INTRODUCTION)

1. "Energy Future." Edited by R. Stobough and D. Yergin, Random House, 1979.

# PART I

## ACTIVE SOLAR ENERGY

Active solar energy systems are generally differentiated from passive designs by their dependence on mechanical devices, such as pumps or blowers, to collect, store, and utilize the incident radiation. With the exception of photovoltaic devices, most employ the flat-plate collector as their principal component. Concentrating and semi-concentrating collectors are also starting to find use in some system designs.

To clarify the assessment, active systems were divided into the following categories:

1. Residential Service Water Heating,
2. Residential Space Heating,
3. Commercial and Industrial Service Water Heating,
4. Commercial and Industrial Space Heating,
5. Ventilation Air Preheating,
6. Swimming Pool Heating,
7. Agricultural and Forest Product Applications,
8. Solar Cooling,
9. Photovoltaics.

CHAPTER 2

# RESIDENTIAL SERVICE WATER HEATING

## 2.1 BACKGROUND INFORMATION

Residential service water heating is now a basic amenity in virtually all Manitoba homes. As of May 1979, there were 242,000 hot water systems installed in single family dwellings in the province (Ref. 1). Current figures are likely very similar. The fuel sources, average energy consumptions, and annual operating costs are summarized in Table 2.1. Manitobans spend approximately $25,000,000 per year to heat service water for residential purposes, exclusive of that used in apartment blocks. This represents approximately 2% of the province's net energy consumption.

According to information supplied by Manitoba Hydro and the Greater Winnipeg Gas Co., the average consumption of hot water is approximately 227 litres (50 imp. gal.) per day per household (Ref. 2,3). This is used primarily for bathing, washing, cleaning, and cooking with maximum consumption occurring daily around 8:00 a.m. and 8:00 p.m. On an annual basis, the consumption of hot water is relatively constant although energy usage follows an annual cycle due to supply water temperature variations. Using the fluctuation of water temperature within the City of Winnipeg water supply system (Ref. 4), an estimate of energy consumption for a residence using electric heating is presented in Table 2.2.

## 2.2 APPLICABLE SOLAR ENERGY SYSTEMS

Several types of systems have been devised to heat residential service water with solar energy. Figures 2.1 and 2.2 show the layout and basic operation of the three most common types: the closed-loop, drain-down and thermosiphoning systems. Their means of operation is basically the same. The heart of the system is the flat-plate solar collector, usually mounted on the roof of the structure. Radiant solar energy falls upon the collector where it is converted into thermal energy (heat). A transport fluid, usually a water and antifreeze solution, is circulated between the collectors and a storage tank preheating the incoming supply water before it reaches the existing hot water tank. As in most solar energy systems, the primary problems are the possibility of freezing the transport fluid, corrosion of the collector and plumbing, leakage, destruction of the collector under extreme temperature conditions and, of course, cost.

Residential solar service water heating systems are generally sized to provide 40% to 70% of the total water heating load. Smaller fractions are avoided because of the poor return on fixed costs for preheat tanks, pumps, plumbing, controls, etc., while higher fractions would necessitate very large collector areas and thermal storage volumes hence giving a poor return per unit of collector area. Figure 2.3 shows the results of a computer simulation that plots the percentage of hot water load (the solar fraction) supplied by a typical solar energy system if installed in Winnipeg. This analysis used the f-Chart computer program, which is a standard design tool for sizing solar energy systems. Notice

TABLE 2.1

SUMMARY INFORMATION ON RESIDENTIAL SERVICE WATER HEATING IN MANITOBA AS OF MAY, 1979

| Fuel | Number Of Residential Applications | Average Annual Energy Consumption (kWh) | Average Annual Energy Cost |
|---|---|---|---|
| Piped Gas | 113,000 | 6,400 | $ 77 |
| Electricity | 126,000 | 5,000 | $127 |
| | 242,000* | | |

Total Provincial Consumption: $1.4 \times 10^9$ kWh
Total Provincial Cost: $25,000,000

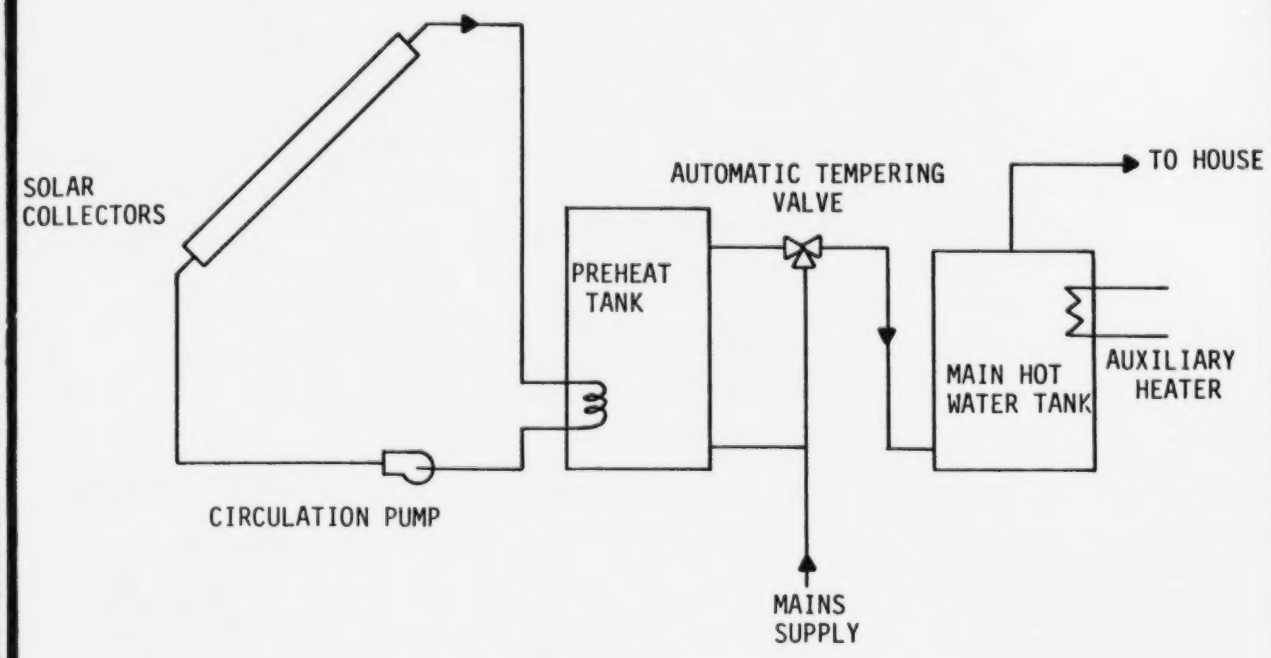
* Summation not exact due to statistical inaccuracies.

(Refs. 1,2)

TABLE 2.2

TYPICAL MONTHLY ELECTRICAL CONSUMPTION OF A DOMESTIC WATER HEATER IN WINNIPEG

| Month | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Consumption (kWh) | 439 | 449 | 449 | 449 | 453 | 425 | 386 | 367 | 367 | 386 | 406 | 425 |

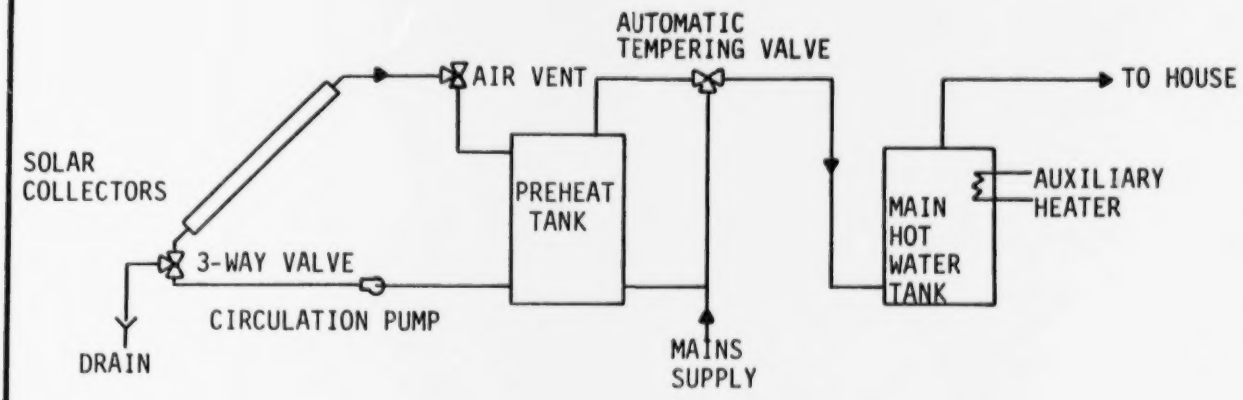



OPERATION: An antifreeze and water solution transfers heat from the solar collectors to the preheat tank through a heat exchanger in (or around) the preheat tank. Incoming cold supply water first goes to the preheat tank and then to the main hot water tank where any additional energy required to reach the temperature set point is supplied. Typically, 3.7 $m^2$ (40 $ft^2$) of collector area is used with a 182 litre (40 imp. gal.) main tank and a 272 litre (60 imp. gal.) preheat tank. This would meet approximately half the hot water requirements of an average Manitoba family of four.

TYPE I

CLOSED LOOP SYSTEM

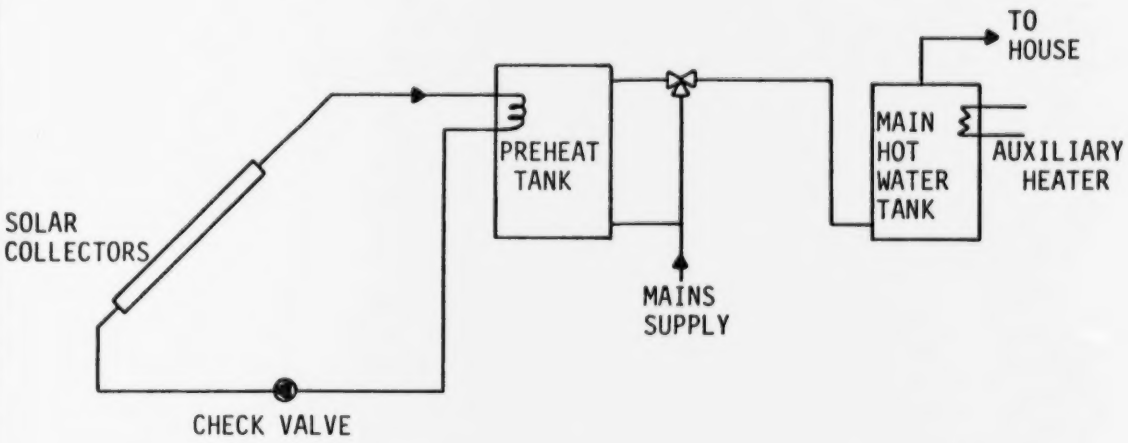
FIGURE 2.1




OPERATION: Similar in size and operation to the closed loop system exccpt freeze protection is supplied by draining the collectors whenever their temperature approaches the freezing point.

TYPE II

DRAIN-DOWN SYSTEM

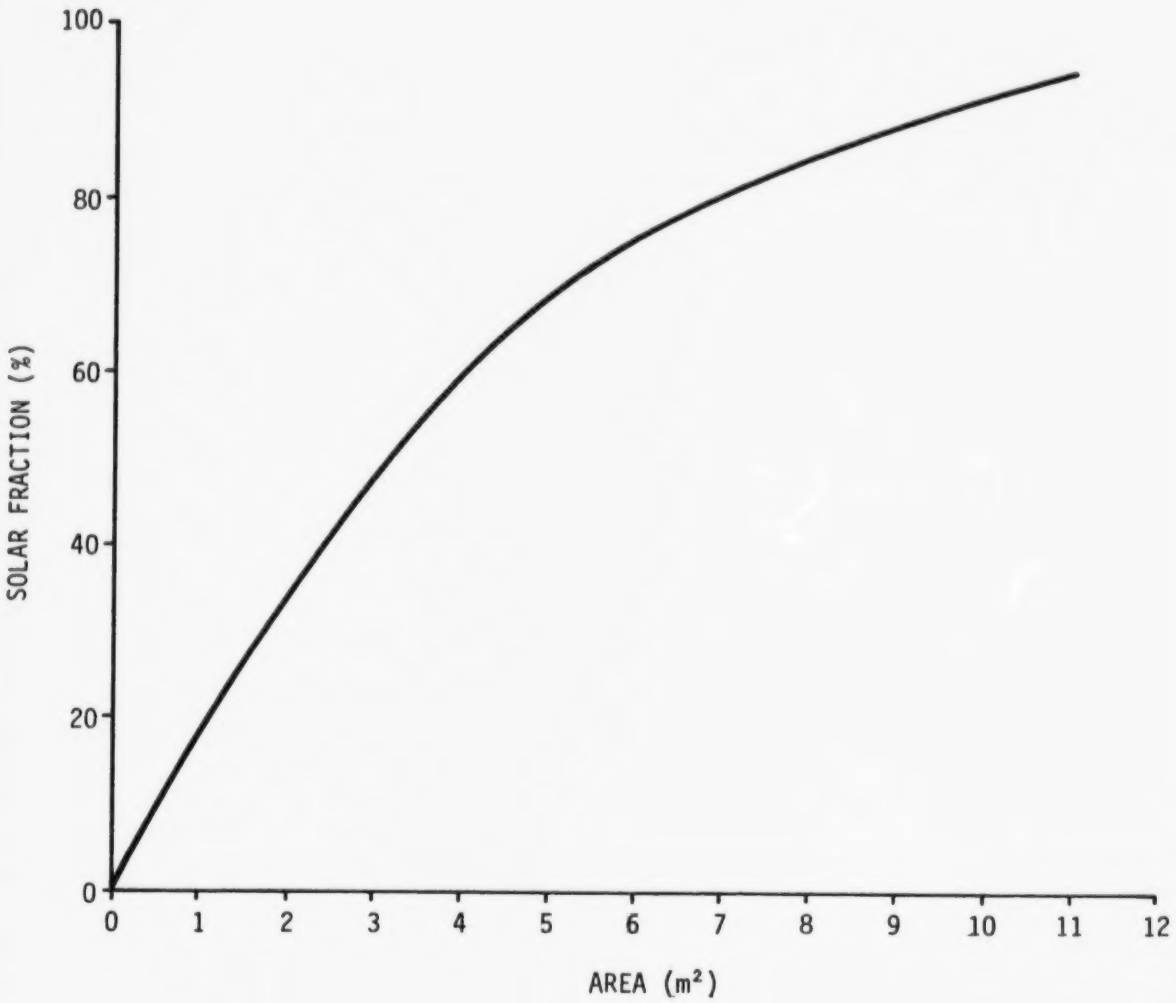



OPERATION: Also similar in size and basic operation to the closed loop system except no pump is used with all circulation through the collectors taking place due to natural convection. Although a very simple and trouble-free design, the preheat tank must be located approximately 0.6 m (2 ft.) above the solar collectors to maintain adequate circulation.

TYPE III

THERMOSIPHONING SYSTEM

FIGURE 2.2




LOCATION - WINNIPEG
COLLECTOR SLOPE - 65°
COLLECTOR AZIMUTH - SOUTH
WATER USAGE - 227 LITRES (50 IMP. GALLONS) PER DAY
WATER SET TEMPERATURE - 49°C (120°F)
COLLECTOR - THERMO SOLAR 'SOLECTOR'
SIMULATION PROGRAM - f-CHART, VERSION 2.0

SOLAR FRACTION AS A FUNCTION OF COLLECTOR AREA FOR A SERVICE WATER HEATING INSTALLATION IN WINNIPEG

FIGURE 2.3

how the curve begins to flatten beyond a solar fraction of approximately 50%.

Using this value of 50%, which is generally attainable and is near the economic optimum, a typical solar-heated residential service water system would save an average of 2,500 to 3,200 kWh of energy per residence per year in Manitoba.

Currently, less than 10 solar-heated residential service water systems are known to be in operation in Manitoba. All of these have been owner-designed and built.

Owner-built systems are generally more cost effective than commercially installed systems since all of the labour and some of the component costs are eliminated. Undoubtedly, many individuals possess sufficient skills (as craftsmen and scroungers) to construct an economically competitive solar water heater. However, most homeowners would not attempt this task. Therefore the emphasis of this discussion is on commercial systems.

System reliability is another factor. There has been little long-term operational experience with residential solar water heating and this has not been totally documented. The literature to date, does highlight some shortcomings of the existing technology when used in Canada (Refs. 5,6). This would no doubt be overcome as the industry matures.

## 2.3 ECONOMICS OF RESIDENTIAL SOLAR SERVICE WATER HEATING

Residential service water heating using solar energy is not cost effective in Manitoba. The 1980 prices of commercially installed systems ranged between $2,400 and $3,300 with an average price of approximately $2,800. Such an installation would provide about 50% of the annual water heating requirements of a Manitoba residence. Using the average system price of $2,800 and February 1981 energy rates, a Winnipeg homeowner using a solar water heater would save approximately $39 in displaced natural gas costs or $63 in displaced electric heating costs. The Simple Payback Periods (SPP) thus become 73 years with gas heating and 44 years with electricity. The return to consumers outside Winnipeg would be similar.

A Life Cycle Cost (LCC) analysis using a Series Present Worth Factor (SPWF) of 20, as discussed in Chapter 1, and the current savings derivable from a solar water heating system would produce a maximum allowable investment ranging from $771 using gas auxiliary heating, to $1,265 using electric auxiliary heating. This is far below the cost of any available commercial system. Also, no allowance has been made for operating expenses, which, if included, would further reduce the maximum allowable investment.

Therefore both the SPP and LCC analyses show that residential service water heating using solar energy is significantly more expensive than using conventional fuels in both the short- and long-term.

The possibility of lower costs is unlikely using existing system design and technology even if mass production of the collectors was employed. Approximately 60% to 80% of the installed system cost is attributable to items such as storage tanks, controls, piping, pumps, insulation, and labour. Since these have been available for many years for numerous nonsolar applications, there is no reason to expect their cost to drop appreciably with an expanding solar industry. It is even debatable how far collector costs can be lowered since they tend to be material intensive. Thus, there is no reason to expect significant reductions in the price of conventional solar water heaters. Unfortunately, it is this technology which is being so energetically pursued within Canada when it appears a more radical approach is required.

Various energy conservation alternatives also erode the prospects of solar service water heating in Manitoba. Obvious measures such as insulating hot water tanks and lines, using flow restrictors, switching to cold water laundering, setting back water tank temperatures, etc. all reduce the load. While the exact savings which these measures will produce vary, average reductions in the order of 25% can be expected. Since these are all inexpensive, maintenance free means of reducing energy consumption, there is no reason for them not to be adopted. This would reduce the utilization and hence attractiveness of the solar option.

Another potential conservation alternative is heat recovery. One such system currently under development by manufacturers in Canada and the United States uses a heat pump to extract energy from the house's waste water to preheat the supply water to the hot water tank. Although the unit has yet to reach the marketplace, it appears capable of meeting 65% of a typical residential hot water load for installed costs ranging from $800 for new construction to $1,200 for retrofits (Ref. 7). This is considerably more cost effective than any known, existing or proposed solar water heater.

One exception to this analysis may be using solar energy to supply hot water for remote sites, such as cottages, where conventional fuels are either expensive or unavailable. This is especially attractive where only summer operation is needed thus allowing the use of simple, inexpensive thermosiphoning systems. Unfortunately, the total size of this market is quite small.

## 2.4 CONCLUSIONS

1. Residential service water heating using solar energy is currently not competitive with conventional fuels nor is it expected to become so within the immediate future. While there may be certain environmental and social advantages, it is highly unlikely many consumers would consider this adequate compensation to offset the additional cost of solar water heating.

2. Existing and potential energy conservation alternatives are more cost effective and should therefore be preferred over solar service water heating.

3. Based on present technology and economics, it is doubtful that the use of residential solar service water heating in Manitoba, will become widespread within the immediate future.

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CHAPTER 3

# RESIDENTIAL SPACE HEATING

## 3.1 BACKGROUND INFORMATION

As of May 1979, there were 231,000 houses and 20,000 row houses in Manitoba (Ref. 1). Table 3.1 shows a breakdown of the principal types of heating systems and fuels used in these dwellings. This shows that hot air furnaces were by far the most common type of heating plant and piped natural gas the most prevalent fuel. Since natural gas service is only available in larger communities, oil or electricity are the common heat sources in rural areas, although there has been an increase in the use of wood burning heaters in the last few years.

Estimating the average cost and consumption of energy for space heating is somewhat difficult due to the tremendous range of possible insulation levels, climatic conditions, house sizes, and fuel costs. There are now modern and comfortable houses within the province whose sole source of heating energy is wood grown on the owner's land; as such it can be argued their space heating cost is zero. On the other extreme, some poorly insulated structures using diesel-generated electric resistance heating have annual heating bills well in excess of $2,000.

However, using average data, it can be estimated that approximately $8.9 \times 10^9$ kWh of energy is consumed annually at a cost of $142,000,000 for residential space heating within the province (for houses and row houses only). This represents approximately 11% of Manitoba's net energy consumption.

## 3.2 APPLICABLE SOLAR ENERGY SYSTEMS

Various types of solar energy systems have been designed to supply space heat in residences. These can be broadly classified as air or liquid systems and are explained in Figures 3.1 and 3.2. They typically supply 20% to 60% of the annual heating load of the structure.

## 3.3 ECONOMICS OF RESIDENTIAL SOLAR SPACE HEATING

Owner-designed and built solar space heating systems can generally be constructed in new residences for $5,000 to $8,000 if some amount of salvaged equipment is used. The collector area would be approximately 46 $m^2$ (500 $ft^2$). This assumes a fair degree of skill and engineering expertise on the part of the owner as well as a willingness to devote considerable time and effort to the project. Commercial systems will typically cost $15,000 to $25,000 on new houses for 46 $m^2$ (500 $ft^2$) of collectors.

Installed on a Winnipeg house, these systems would normally supply about 60% of the space heating requirements. This figure decreases somewhat as one moves north.

TABLE 3.1

PRINCIPAL RESIDENTIAL HEATING EQUIPMENT
AND FUELS AS OF MAY, 1979

PRINCIPAL HEATING EQUIPMENT*

| | | |
|---|---|---|
| Hot Air Furnaces (oil, piped gas or electric) | 191,000 | 76% |
| Electric Baseboards | 33,000 | 13% |
| Steam or Hot Water | 16,000 | 6% |
| Heating Stoves | 10,000 | 4% |

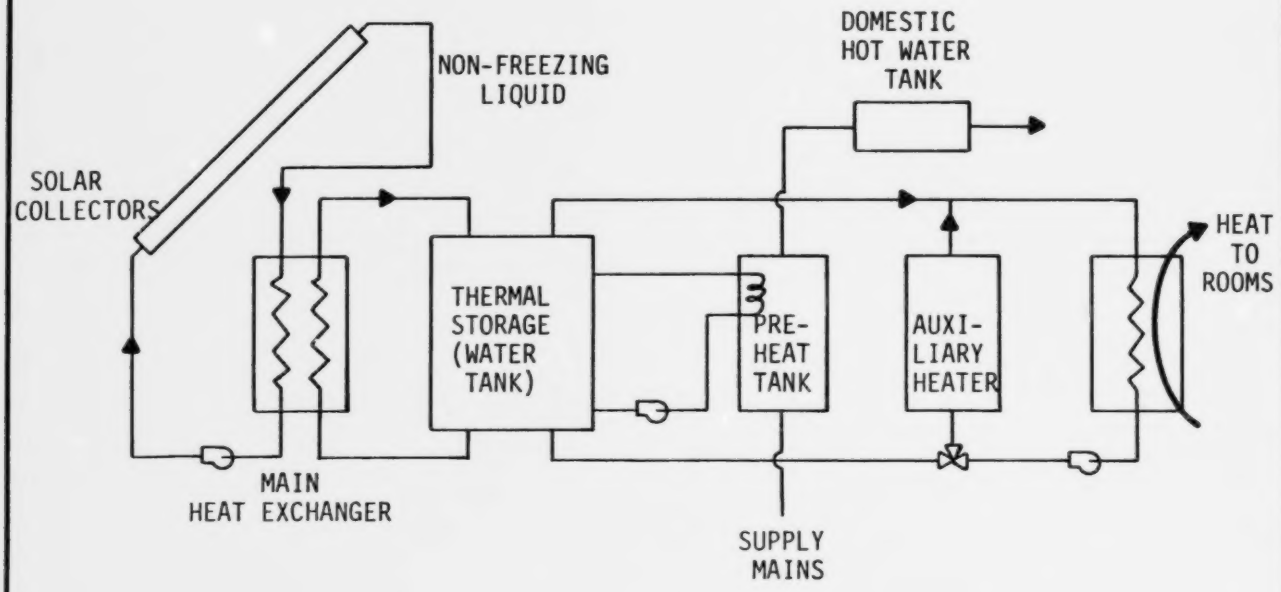
PRINCIPAL HEATING FUEL*

| | | |
|---|---|---|
| Piped Gas | 143,000 | 58% |
| Oil & other Liquid Fuels | 60,000 | 24% |
| Electricity | 42,000 | 17% |

Total Single Dwelling Households - 251,000

(Summation not exact due to statistical inaccuracies)

* All data is for single family dwellings only.

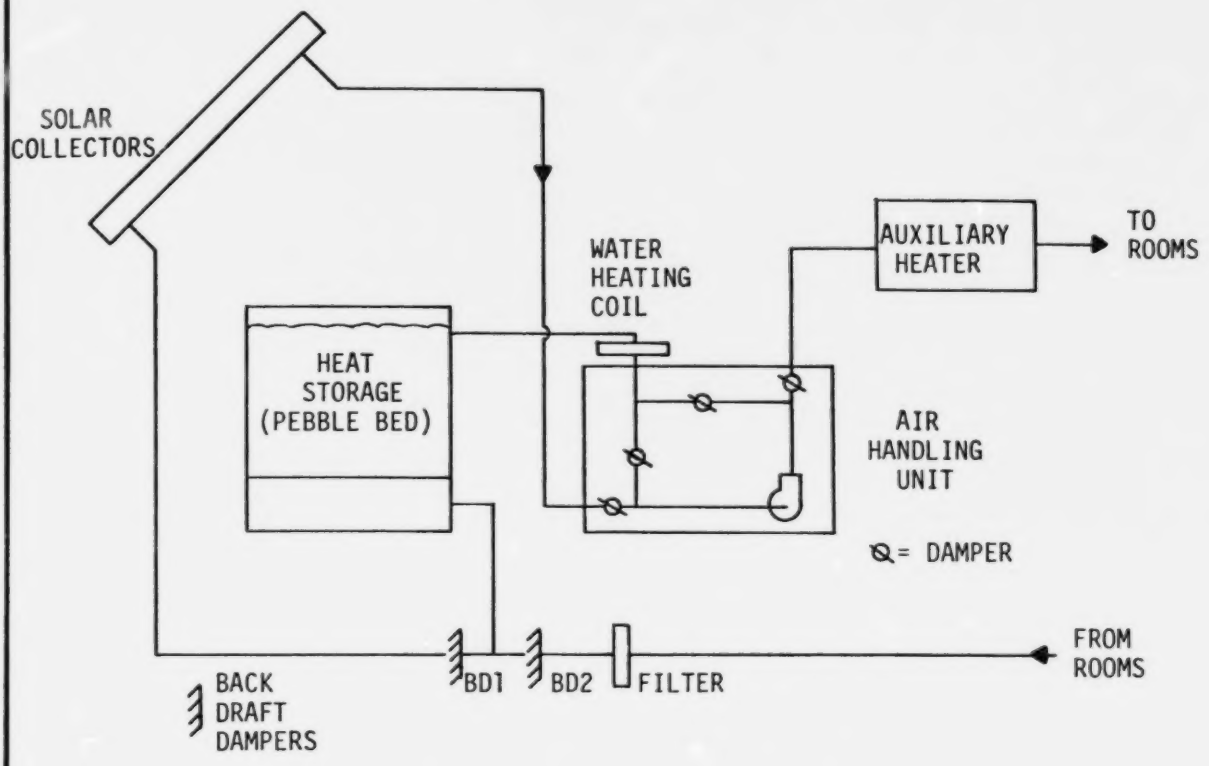



OPERATION: Heat absorbed by the solar collectors is transferred to the thermal storage through the main heat exchanger which separates the antifreeze solution in the collectors from the storage water. Energy is extracted from the storage as required to maintain room temperature with any additional heat being supplied by the auxiliary heater. A preheating system for the domestic hot water tank is also usually included.

LIQUID BASED RESIDENTIAL

SPACE HEATING SYSTEM

FIGURE 3.1




OPERATION: Hot air from the collectors is drawn through the air handling unit which uses four dampers to supply heat to the rooms or charge the storage. Energy is extracted from the storage by reversing the air flow through the pebble bed thus maintaining thermal stratification. A water heating coil is used to preheat the domestic hot water.

AIR BASED RESIDENTIAL

SPACE HEATING SYSTEM

FIGURE 3.2

Table 3.2 uses these values to show the range of Simple Payback Periods (SPP) possible for residential solar space heating systems in Winnipeg. System costs were set at $6,500 for owner-built designs and $20,000 for the commercially installed systems. These figures are considered representative of the current prices. The SPP varies from 13 years for an owner-built design displacing oil to 85 years for a commercial system replacing natural gas. Payback periods outside of Winnipeg would be longer due to higher construction costs and reduced energy collection (in the north).

Table 3.3 shows the results of a Life Cycle Cost (LCC) analysis to determine the maximum investment which could be justified for the solar energy systems using a Series Present Worth Factor (SPWF) of 20. To be considered economic, these systems would have to be installed for $4,200 to $8,520 depending upon the type of auxiliary fuel. Comparing these to the actual costs shows that only owner-built systems would prove justifiable if a SPWF of 20 is considered appropriate. However, commercially installed systems would not be considered economic under any circumstances.

Both these methods of analysis point to the same conclusion. Using the assumed solar energy system costs of $6,500 (owner-built) and $20,000 (commercial), only the owner-built designs have any possibility of competing against conventional fuels within the immediate future.

Significantly lower solar energy system costs appear unlikely. Approximately 60% to 80% of the total installed cost is attributable to standard mechanical components (i.e. exclusive of the collectors) or labour. Since the costs are largely fixed by production for nonsolar industries, there is little hope for large price reductions. The major cost savings will undoubtedly be through the use of better design practices to eliminate or simplify many of the current components. However, because a minimum level of sophistication is necessary for the system to perform its desired functions of collecting, storing, and properly utilizing the incident radiation, the chance of significant cost reductions does not appear promising. Also, no provision has been made for operating expenses which can drastically reduce the benefits of the solar energy system. Therefore, in summary, commercially designed, constructed, and installed residential solar space heating in new dwellings in Manitoba is not economically competitive against conventional fuels for the immediate future.

Retrofitting active solar space heating systems into existing dwellings is another possibility. Unfortunately, the capital costs are generally higher due to the inherent problems of working in a finished structure. Disruptions to the living area (particularly the basement), possible foundation problems due to the thermal storage, shading from adjacent structures or vegetation, and improper orientation plus other potential problems have to be considered. In general, the cost and inconvenience of retrofits are greater than for new construction.

One type of retrofit system now commercially available employs a small 1.5 $m^2$ (17 $ft^2$) collector attached directly to existing walls to supply warmed air to the living space. Since the solar fraction sup-

TABLE 3.2

SIMPLE PAYBACK PERIODS FOR RESIDENTIAL SOLAR SPACE HEATING SYSTEMS IN WINNIPEG (FEB./81)

| Auxiliary Fuel | Annual Heating Cost Without Solar Energy System (1) | Reduction in Annual Heating Cost Due To Solar Energy System (2) | Simple Payback Period Owner-Built System (3) | Simple Payback Period Commercially Installed System (4) |
|---|---|---|---|---|
| Natural Gas | $392 | $235 | 28 years | 85 years |
| Oil | $853 | $512 | 13 years | 39 years |
| Electricity | $557 | $334 | 19 years | 60 years |

NOTES:

1. For a typical house with a heating requirement of 3.4 kWh/celsius degree day.
2. Solar fraction equals 60%.
3. Assuming a system cost of $6,500.
4. Assuming a system cost of $20,000.

TABLE 3.3

LIFE CYCLE COST ANALYSIS OF RESIDENTIAL SOLAR SPACE HEATING SYSTEMS IN WINNIPEG (1,2) USING AN ASSUMED SERIES PRESENT WORTH FACTOR (SPWF) OF 20 (FEB./81)

| Auxiliary Fuel | Owner-Built Systems | | Commercially-Installed Systems | |
|---|---|---|---|---|
| | Maximum Justifiable System Cost | Current System Cost | Maximum Justifiable System Cost | Current System Cost |
| Natural Gas | $ 4,700 | $6,500 | $ 4,700 | $20,000 |
| Oil | $10,240 | $6,500 | $10,240 | $20,000 |
| Electricity | $ 6,680 | $6,500 | $ 6,680 | $20,000 |

NOTES:

1. For a typical house with a heating requirement of 3.4 kWh/celsius degree day.
2. Solar fraction equals 60%.

plied is typically in the order of 5%, no thermal storage is required. Although quite a simple design, the installed cost is quoted as $750, and would provide savings ranging from $13 to $29 per year (i.e. a SPP of 26 to 58 years) depending on the fuel being displaced.

Therefore, retrofitting commercially installed residential solar space heating systems in existing Manitoba dwellings does not appear to be competitive against conventional fuels.

Notice that the conclusions regarding the economics of commercial systems for new or retrofit applications is fairly insensitive to the installed system cost. Drastic price reductions would be necessary to alter these conclusions.

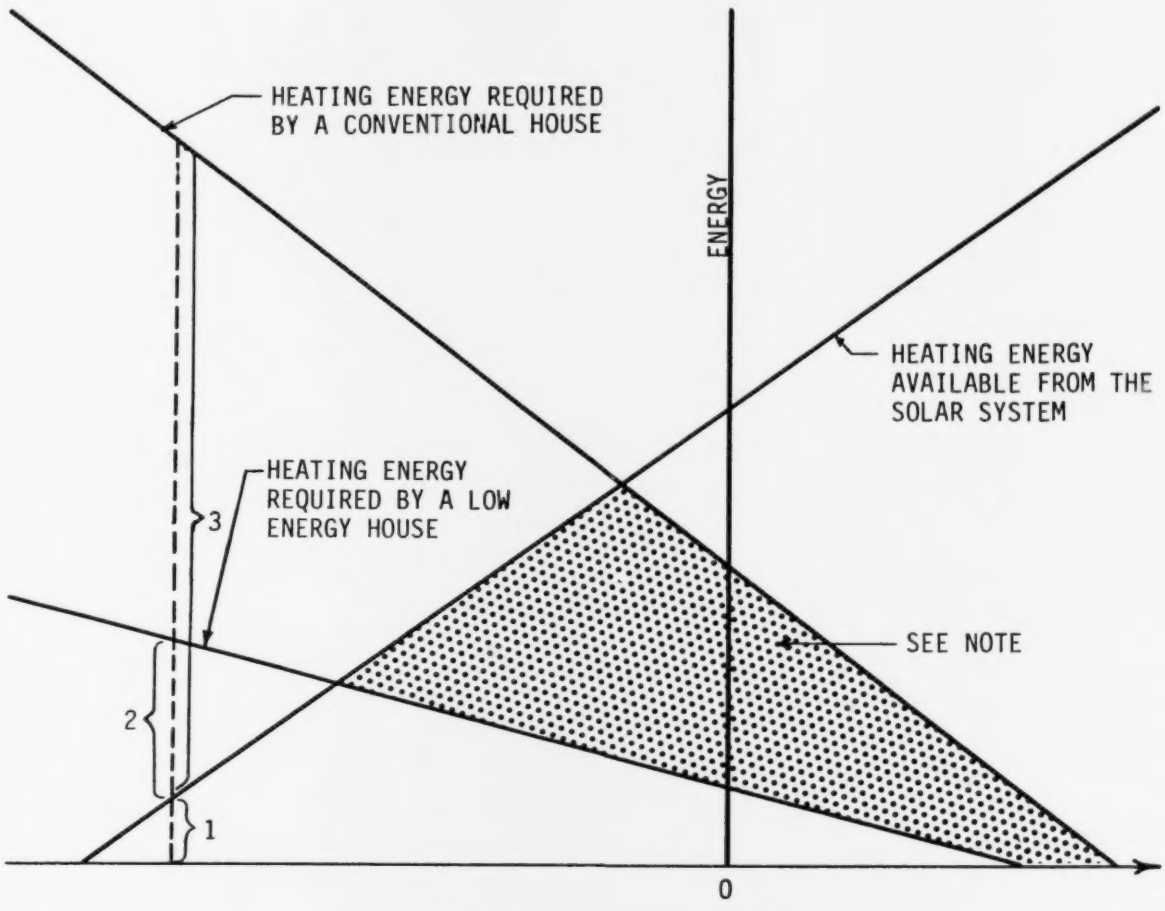
Energy conservation alternatives also provide extremely stiff competition for residential solar space heating. It is now possible to construct low energy houses utilizing extremely high insulation levels and virtually air-tight air/vapor barriers which cut the space heating load by 80%. Commercially, these features would add approximately 10% to 13% to the basic house price (i.e. exclusive of the land costs). This could be reduced somewhat for owner-built structures.

Typical new, commercially-built houses cost approximately $40,000 exclusive of land, thus the extra conservation features would add approximately $4,000 to $5,000 to the price and save 80% of the heating bill. In comparison, a solar heating system would cost approximately $20,000 and save at best 60% of the heating bill in Winnipeg. Also, the operating costs associated with the conservation features in low energy housing would be less than those for a solar energy system.

New and more efficient furnaces are now commercially available. These offer excellent returns on investment and would also reduce the possible savings derivable from solar energy systems.

Generally the heating loads in existing structures can be reduced by 20% to 50% at reasonable cost by simple conservation measures designed to reduce air infiltration, increase insulation levels, or upgrade furnace efficiency. Moving north, the advantages of energy conservation over active solar energy become even more pronounced.

One final point about conservation should also be made. It is often stated that solar space heating systems work best with high conservation levels. In fact, the exact opposite is true as illustrated in Figure 3.3. The two curves sloping down to the right plot the energy required for space heating as a function of outside air temperature for a conventional and a low energy house. The curve sloping up to the right shows the energy available from a hypothetical solar heating system installed on each house. The energy to be supplied by the furnace is the difference between the two lines. Because the low energy house's demand curve is so much lower, useful heat can only be extracted from the solar system at very low outdoor air temperatures, when the solar system is operating at a low efficiency. At higher outdoor temperatures when the solar system can provide significant quantities of heat, the low energy house's demand becomes quite minimal. Therefore, maximum




1. Heating energy available from the solar energy system.
2. Heating energy which must be supplied by a low energy house's auxiliary furnace.
3. Heating energy which must be supplied by a conventional house's auxiliary furnace.

NOTE: The shaded area represents the heat available from the solar energy system which the conventional house can use but the low energy house cannot , thereby lowering the utilization of the solar energy system.

RELATIONSHIP BETWEEN AVAILABLE SOLAR ENERGY AND CONSERVATION FOR RESIDENTIAL SPACE HEATING

FIGURE 3.3

utilization of a solar system would be obtained if it were installed on a very poorly insulated structure. The more energy conserving the structure, the poorer the return from the solar system.

## 3.4 CONCLUSIONS

1. Residential space heating using commercially installed solar energy systems in Manitoba is not competitive against heating systems using conventional fuels.

2. Neither commercial nor owner-built solar heating systems are economically competitive against proven energy conservation alternatives.

3. Based on present technology and economics, it is doubtful that the use of residential solar space heating in Manitoba will become widespread within the immediate future.

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CHAPTER 4

# COMMERCIAL AND INDUSTRIAL SERVICE WATER HEATING

## 4.1 BACKGROUND INFORMATION

Due to the number of possible applications and the sparse nature of statistical data available, it is difficult to obtain quantitative estimates of either how much energy the province consumes for process water heating or what impact solar energy could have in meeting these needs. Service water is required for cleaning, laundry, food production, processing, sterilizing, and numerous other uses.

## 4.2 ECONOMICS OF COMMERCIAL AND INDUSTRIAL SOLAR SERVICE WATER HEATING

Due to the wide diversity of applications, it is difficult to generalize about the economics of process water heating. However, costs for some process water solar heating systems installed in Canada during 1977-'79 ranged from $\$537/m^2$ to $\$947/m^2$ of collector area (Ref. 1).

Table 4.1 outlines some of the characteristics of an economic process water heating application. Where these conditions are met, and where the design is well suited to the application, it appears to be possible to obtain a Simple Payback Period (SPP) of less than ten years. On the other hand, a solar process water heating system similar in design to a typical domestic water system, and meeting a large fraction of a small, intermittent load can easily have a payback period of over 100 years.

Two systems presently operated in Manitoba have estimated SPP's of 15 years and 33 years respectively.

In the United States, a number of economic solar process water systems have been installed. One such system provides process water for a uranium milling operation in a remote location in New Mexico (Ref. 2). It uses a 10 cm (4 in.) deep-lined pond, with a plastic cover. This pond is filled each morning and drained as required. The system efficiency is on a par with that of conventional solar energy systems and the installed cost was only \$75 per $m^2$ ($\$7/ft^2$) three years ago, making it an economic investment.

Table 4.2 and Figure 4.1 show how the SPP can be calculated as a function of available solar radiation, solar system efficiency, price of energy and system cost. Radiation data is shown for Winnipeg and Thompson (for comparison purposes), both on a horizontal surface (for pond type designs) and at 65° from the horizontal (for more efficient energy collection and snowshedding).

Knowing the maximum solar energy available and a reasonable estimate of system efficiency, the reduction in energy costs can be calculated. Then using the bottom graph of Figure 4.1 with the system cost, the Simple Payback Period can be found. Since the number of variables

TABLE 4.1

CHARACTERISTICS OF AN ECONOMIC SOLAR APPLICATION

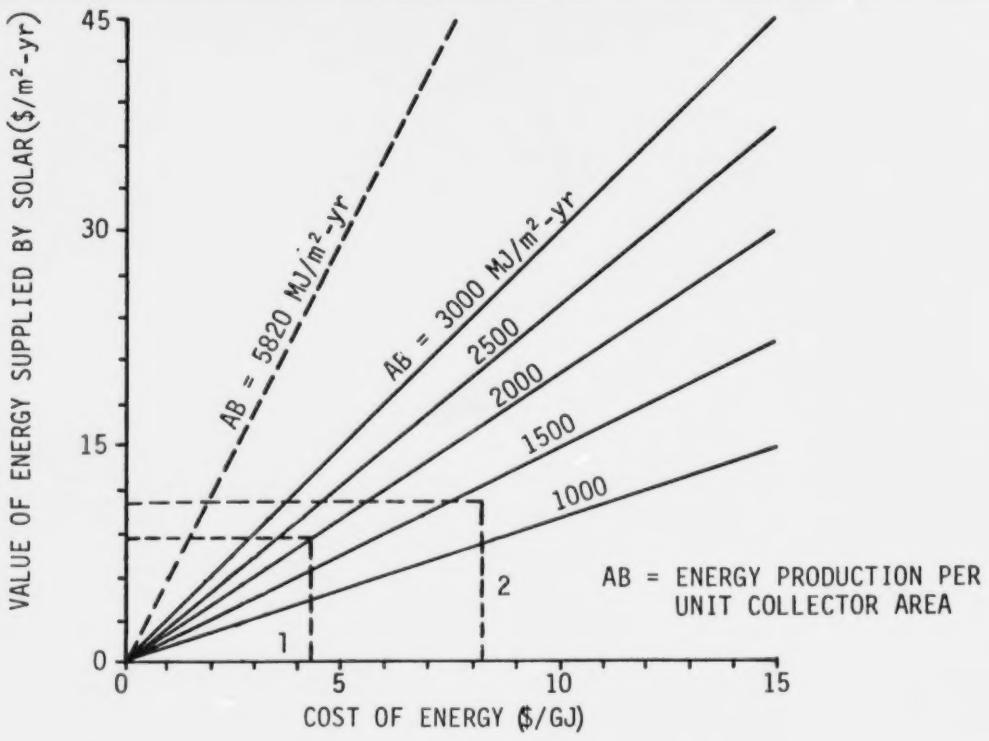
* Expensive auxiliary fuel (e.g. electricity, oil or propane)
* Low collector fluid inlet temperature
* Large load at low temperature
* Continuous load throughout year
* Zero storage capacity required
* Easy mounting of collectors (e.g. on existing vertical wall)
* Available maintenance staff (e.g. factory environment)
* Large solar system required (for economies of scale)
* Small solar fraction (to minimize wasted energy)
* Appropriate for the use of low cost solar collector panels

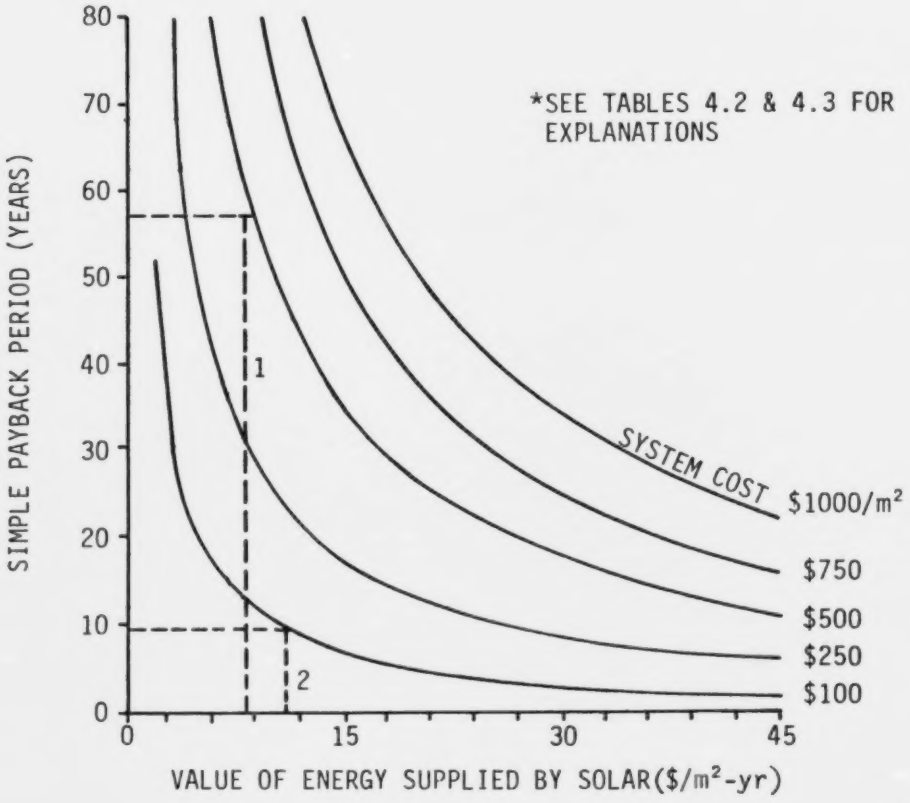
TABLE 4.2

DELIVERED SOLAR RADIATION
FOR WINNIPEG AND THOMPSON

| | A Incident Solar Radiation $MJ/m^2$-Yr | | B Assumed System Efficiency | A x B $MJ/m^2$-Yr |
|---|---|---|---|---|
| Location | Horizontal (April-October) | 65° (All Year) | | |
| Winnipeg | 3800 | | 30% | 1140 |
| | 3800 | | 40 | 1520 |
| | 3800 | | 50 | 1900 |
| | | 5820 | 30 | 1746 |
| | | 5820 | 40 | 2328 |
| | | 5820 | 50 | 2910 |
| | | 5820 | 100* | 5820* |
| Thompson | 3590 | | 30% | 1077 |
| | 3590 | | 40 | 1436 |
| | 3590 | | 50 | 1795 |
| | | 5900 | 30 | 1770 |
| | | 5900 | 40 | 2360 |
| | | 5900 | 50 | 2950 |
| | | 5900 | 100* | 5900* |

* Maximum available solar energy incident on one square meter of collector.




SIMPLE PAYBACK PERIODS FOR PROCESS WATER HEATING SYSTEMS

FIGURE 4.1

is so large, the range of payback periods is significant. However, the two scenarios developed in Table 4.3 and in Figure 4.1, that of a service water system for an office building displacing natural gas and an inexpensive pond design displacing electricity, represent the possible extremes. As shown in Figure 4.1, these two applications produce simple payback periods of 57 and 9 years respectively.

Process water heating loads can be significantly reduced using various proven energy conservation strategies and technologies. These include heat recovery systems, temperature setbacks, the reduction of actual water requirements, etc. Most conservation schemes for process water heating have a SPP of five to ten years. Since the effects of future prices apply equally to solar and conservation, it would appear that the conservation option is generally more economic except when very low cost solar energy designs can be efficiently applied.

## 4.3 CONCLUSIONS

1. Commercial and industrial service water heating using solar energy in certain commercial and industrial service water heating applications, would be competitive against conventional fuels.

2. Any consideration of using solar energy for this application should include an economic comparison with applicable energy conservation alternatives.

TABLE 4.3

EXAMPLE OF TWO SOLAR PROCESS WATER APPLICATIONS

SYSTEM 1

Application: service water heating for an office complex

Location: Winnipeg

Type of System: closed-loop glycol

Tilt: 65°

System Efficiency: 35%

Utilization: all year

System Cost: 500 $/m$^2$ (46 $/ft$^2$)

Type & Cost of Auxiliary Fuel: natural gas @ 3.393¢/ccf, 75% efficiency

SYSTEM 2

Application: batch water heating (e.g. for a fish hatchery)

Location: rural southern Manitoba near Winnipeg

Type of System: pond

Tilt: 0°

System Efficiency: 35%

Utilization: April 1st to October 31st

System Cost: 100 $/m$^2$ (9 $/ft$^2$)

Type & Cost of Auxiliary Fuel: electricity @ 2.97¢/kWh

## REFERENCES

(COMMERCIAL AND INDUSTRIAL
SERVICE WATER HEATING)

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# CHAPTER 5

## COMMERCIAL AND INDUSTRIAL SPACE HEATING

### 5.1 BACKGROUND INFORMATION

Commercial and industrial structures vary in size from a few hundred square metres to large factory and office complexes with hundreds of thousands of square metres of useable floor area. The energy budgets will range from a few hundred to well over a million dollars per year.

The space heating loads of the smaller buildings are generally comparable to those of houses. However, as the size of the structure grows, the heating load per unit area of floor space starts to decline. This is because the ratio of exterior building surface area to internal volume decreases with increasing building size. The effects of internal sources of heat generation such as lights, equipment and people then become more pronounced. The result is that in very large structures, the actual heat loss through the exterior envelope constitutes only a small percentage of the total energy requirements of the building. Aside from that used for lights and equipment, the remainder of the energy budget will be expended on the control of space temperature by the central heating and ventilating system. This usually consumes a large amount of energy because it is done by overcooling and subsequently reheating large volume air streams to maintain desired environmental conditions.

Smaller structures, say those up to 500 $m^2$ (5,380 $ft^2$) in size, would generally use solar space heating systems similar in design to those employed for residential applications. The auxiliary heating plant is typically a single furnace or boiler supplying heat on demand. In larger buildings, the heating and ventilating systems become more centralized and complex. Most of the heating energy is supplied by steam or hot water coils and baseboards.

### 5.2 ECONOMICS OF COMMERCIAL AND INDUSTRIAL SOLAR SPACE HEATING

Referring to Table 4.1, it is obvious that commercial and industrial space heating has few of the characteristics of an optimum solar load. First, the fuel source is generally natural gas, thereby minimizing the auxiliary heating costs. Second, the collector fluid inlet temperature has to be relatively high, with the lowest possible temperature being that of room air, thus reducing collector efficiency. Third, while the load may be relatively large, it is required at comparatively high temperatures, again reducing efficiency. Also, the load is seasonal so that the solar system cannot provide useable energy for at least half the year. Storage would generally be required thus increasing costs. All of these factors working in concert will typically produce high system costs and hence, a high cost for the delivered energy.

Costs for five commercial solar space heating systems constructed on new buildings in Canada during the period 1977-'79 are shown in Table 5.1 (Ref. 1). These compare closely to American experiences with

TABLE 5.1

CANADIAN SOLAR COSTS 1977-'79 FOR
COMMERCIAL AND INDUSTRIAL SPACE HEATING

| Project | Collector Area $m^2$ | Cost $/m^2$ |
|---|---|---|
| Public Archives, Halifax | 604 | 506 |
| Federal Office Building | 1,640 | 420 |
| Federal Office Building | 930 | 506 |
| Applewood School | 230 | 646 |
| Aylmer Senior Citizens Home (Seasonal Storage) | 221 | 1,012 |

(Ref. 1)

commercial, industrial and institutional space heating using solar energy. Their reported average costs for 59 systems installed on a variety of types of structures during 1976-'77 was $\$510/m^2$ (Ref. 2).

Systems similar to those mentioned above would operate with efficiencies of approximately 30% if installed in Winnipeg. If they were displacing natural gas being burned at an efficiency of 75% and the previous system costs were brought forward to current prices using an inflation rate of 10% per year, the Simple Payback Period (SPP) would range from 140 to 340 years. Obviously, existing systems are far from economic when displacing natural gas, the most commonly used auxiliary fuel. The use of Life Cycle Costing would not alter these conclusions.

At present there are no known economic solar space heating operating systems in commercial or industrial applications in Canada or the northern United States. Commercial and industrial space heating loads can usually be reduced drastically through properly applied energy conservation measures. Such steps as minimizing the volume of outdoor air admitted to the structure, eliminating simultaneous heating and cooling of air streams, improved control system strategies and the upgrading of insulation will produce SPP's for the energy conservation alternatives of under 15 years and, in most cases, under three.

Therefore it is unlikely that most building owners would install a solar space heating system under current conditions. If solar energy is to ever become a reasonable investment, a new design approach which significantly reduces installed system costs or improves performance will be required. At present, there is no indication that such a breakthrough will be forthcoming within the immediate future.

Reference 1 includes the following breakdown of system costs for the previously mentioned Canadian installations:

| | |
|---|---|
| Collector Costs | 25% to 40% |
| Mechanical Costs | 35% to 50% |
| Structural costs | 10% to 20% |
| Controls Costs | 5% to 10% |

Mechanical (piping, pumps, heat exchangers, tanks, etc.), structural, and controls costs constitute the bulk of the total installed price. Even if significant reductions in the collector price could be realized, the total system cost would not be significantly improved.

## 5.3 CONCLUSIONS

1. Commercial and industrial space heating using solar energy is not currently competitive against conventional fuels.

2. Numerous energy conservation alternatives exist which offer dramatically superior returns on investment.

3. There is little likelihood commercial and industrial solar space heating will become viable unless new design approaches which significantly improve the cost effectiveness can be found and adopted.

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2. Corcoran, W.L., "Economics of Solar Heating and Cooling Systems." ASHRAE Journal, April 1978.

CHAPTER 6

# VENTILATION AIR PREHEATING

## 6.1 BACKGROUND INFORMATION

Numerous industrial and commercial operations require large volumes of fresh air to be introduced into the work environment or into production processes. For example, factories often exhaust contaminated air on a continuous basis during working hours to maintain air purity. Restaurants and food processing plants exhaust air to remove moisture, grease and odors from the structure. Indoor swimming pools and animal barns use it as a means of maintaining humidity at acceptable levels.

All of these operations will require fresh air to replace the exhaust air. Since fresh air is at the ambient temperature, it can constitute a significant heating load and create a source of drafts and chills if not properly conditioned before entering the occupied airspace. Normally, make-up air is first heated or mixed with warm air and then allowed to enter the building's air distribution system.

## 6.2 ECONOMICS OF VENTILATION AIR PREHEATING

Ventilation air preheating is one of the best potential applications of solar energy because the low collector inlet temperature results in high operating efficiencies. Even low cost collectors can function at efficiencies of 50 to 65% under these conditions. As well, the load requirements for most industrial applications occur during the day, thus eliminating the need for storage. This in turn minimizes the control system costs and generally improves overall reliability. Since many structures will have large areas of exposed south-facing walls, the collectors can usually be mounted onto or incorporated directly into these surfaces. Although this reduces the solar radiation incident on the collectors by about 10% (from the optimum tilt angle) over the heating season, it all but eliminates the structural costs. Finally, since most applications are factory environments, trained maintenance personnel are normally available to service the solar energy system.

It should be noted however, that the foregoing does not apply to structures such as office buildings which have significant amounts of internal heat generation and comparatively small fresh air requirements. In these cases, outside air is used not only for ventilation purposes but also to prevent overheating of the building's core. Preheating of any form would be of little value in these situations.

A lack of statistical data prevents an accurate estimate of how much energy Manitoba consumes for ventilation air preheating.

Perhaps because of its rather striking simplicity, very little attention has been paid to this application within the solar industry. As such, hard system costs are sparse and estimates must be used.

Currently, most solar preheating systems use commercially available air collectors intended for conventional space heating applications. These would cost at least \$215/$m^2$ (\$20/$ft^2$), installed. Total system costs could be kept at this level if a suitable south wall were available and the system did not require extensive ducting or control strategies. If the system were displacing natural gas in southern Manitoba and the collectors were of high quality, they would produce savings of approximately \$7.70/$m^2$ (\$0.70/$ft^2$) per year over the course of the heating season. If electricity, oil or propane were being displaced, the savings would average around \$19.90/$m^2$ (\$1.85/$ft^2$). Although the economics are better than for most other solar applications, the payback is not yet high enough to attract industrial investors.

Current system costs are not indicative of what could be attained with a low cost collector designed specifically for preheating. By eliminating many of the unnecessary components found in standard air collectors such as the second layer of glazing and back insulation and designing the unit for site assembly, a total system cost of perhaps \$108/$m^2$ (\$10/$ft^2$) or less is feasible.

Computing the energy savings from a solar preheater can be done in a manner similar to that which was used for process water heating in Chapter 4. Using this procedure, two scenarios were developed, that for a low price collector (\$108/$m^2$) displacing electricity at 2.97¢/kWh and an expensive collector (\$215/$m^2$) displacing natural gas at 3.393¢/ccf with a combustion efficiency of 75%. This analysis was restricted to Winnipeg. Simple Payback Periods ranged from 8 years for the low cost collector to 23 years for the expensive collector. Therefore, preheating of make-up air appears to be potentially economic in certain applications.

One very attractive potential application is preheating make-up air for agricultural structures such as hog or poultry barns. These buildings normally have very high exhaust air rates to maintain the humidity at acceptable levels. Simple solar preheaters which use the existing structure's exterior face as the absorber surface could potentially be installed to produce Simple Payback Periods of under five years.

Energy conservation can also be used to effectively reduce make-up air heating loads. A careful analysis of ventilation requirements will often show exhaust air rates to be excessive. These can usually be reduced at zero cost. Heat recovery systems can also be used to reduce the preheating load by recovering a portion of the energy in the exhaust air stream. However, because the contaminant levels may be quite high, filtration and cleaning systems often have to be installed in conjunction with the actual heat exchanger or recovery device. In severe environments such as restaurant exhausts, degreasing and fire protection systems may also be required. Also, bypass ducts or preheat coils may be necessary to control freezing of the heat exchanger. All of these factors generally result in Simple Payback Periods of around five to ten years for exhaust air heat recovery systems, which is comparable to that of the low cost solar preheater. This appears then, to be an application where active solar is competitive with energy conservation alternatives.

Interestingly, there is a possibility the two may work well together in certain situations. As mentioned, some form of mechanical device must often be provided to prevent heat exchanger freezing. If this protection could be provided by the solar preheater, it would not only be saving energy but also reducing capital costs. This concept would have to be carefully investigated though, before it could be recommended.

## 6.3 CONCLUSIONS

1. The introduction of a low cost solar collector designed for preheating could make this application more competitive against conventional fuels for many commercial, industrial, and agricultural plants in the near future.

2. With a low cost collector the paybacks of solar preheating and energy conservation alternatives would be roughly comparable. As such, preheating could become more prevalent in the next five to ten years as fuel prices rise.

3. Ventilation air preheating could often be easily and economically incorporated into new plant and factory construction and should be considered when there is a significant exhaust air load.

4. Any consideration of using solar energy for this application should include an economic comparison with applicable energy conservation alternatives.

CHAPTER 7

# SWIMMING POOL HEATING

## 7.1 BACKGROUND INFORMATION

### Outdoor Pools

Outdoor swimming pools owned and operated by municipalities are normally operated only in July and August. Most of them are heated. Privately owned outdoor pools are normally operated from about May 15th to September 15th. They are usually heated to about 26 C (79°F).

Outdoor pools lose heat due to evaporation, long wavelength radiation and convection and conduction, the first two being the most significant. They gain heat due to solar radiation onto the water surface during the day. The mass of a swimming pool is large enough that daily fluctuations in temperature are not large. A typical outdoor swimming pool kept at 26 C (79°F) will use about 600 kWh/$m^2$ (190,000 Btu/$ft^2$) of heat during a four month season in southern Manitoba.

In small swimming pools, the net heat loss may be sharply reduced by covering the pool with a plastic sheet (solar blanket) when it is not in use. This sheet prevents evaporation losses and slightly improves the net radiation balance. Allowing a pool to cool down between uses will also reduce the heat loss.

### Indoor Pools

Indoor swimming pools lose less heat per unit time and area than outdoor pools. The main mechanism for heat loss is evaporation, due to the fact that the relative humidity of the air over the pool is maintained at about 55%. The rate of heat loss at typical conditions, 26 C (79°F) water and 26 C (79°F) air at 55% relative humidity, is about 180 W/$m^2$ (60 Btu/$ft^2$hr). Although this is lower than for an outdoor pool, the longer season will result in an annual heat requirement double that of an outdoor pool of the same size operated for four months.

## 7.2 APPLICABLE SOLAR ENERGY SYSTEMS

Two types of solar energy systems have been applied to swimming pool heating: unglazed plastic collectors with a direct cycle and glazed metal collectors with a freeze protection system. The first type is used only in summer where freeze protection is not required and where a high heat loss coefficient is not a problem. They may be used with outdoor pools which are operated only in summer or with indoor pools which will be provided with other forms of heat during the winter. The performance of the solar energy system will be slightly better for indoor pools (because the heating load is more evenly spread over the summer months) but the economics favour application to outdoor pools because the capital cost of the heating equipment can be saved.

The second type of solar heating system, using glazed collectors and freeze protection, is not required for outdoor pools which are only used in summer. Its only application is to indoor pools. However, an economic comparison of the two types of systems favours the unglazed plastic collectors. Plastic collector systems are now being installed in Winnipeg for about $\$60/m^2$, while glazed metal collector systems with a glycol-filled primary circuit are being installed for \$650 to $\$900/m^2$.

## 7.3 POTENTIAL APPLICATIONS IN MANITOBA

### Outdoor Pools

It is estimated (Ref. 1) that there are 250,000 swimming pools of over 5,000 l (1,100 gal.) in Canada, of which about 240,000 are residential outdoor pools. There are about 5,000 residential indoor pools, 4,000 institutional outdoor pools, and 1,500 institutional indoor pools. Of these pools, about 5% are in the prairie provinces.

Recent building permits indicate that 47% of the pools built on the prairies are built in Manitoba. This indicates that there are about 6,000 residential outdoor pools in Manitoba. During 1979, over 400 new residential pools were installed. It is estimated that there are about 150 institutional outdoor pools in Manitoba.

If an average pool area of 43 $m^2$ (460 $ft^2$) is assumed, the annual heating requirement of a typical uncovered outdoor pool in Manitoba will be 25,800 kWh ($88 \times 10^6$ Btu) and the total annual heating load of all the outdoor pools in Manitoba would be about 160,000 MWh ($550 \times 10^9$ Btu) if all the pools were uncovered.

The energy saving which results from a solar blanket depends on the type of blanket and on how it is used. There is little data available, but one test has shown that a pool with a solar blanket on it had one-quarter of the heat loss of a bare pool.

In Manitoba almost all new pool purchasers buy a solar blanket. There is no information about the total number of pool blankets in Manitoba, but a national survey indicated that about 65% of all private outdoor pools have solar blankets. This means that the actual energy use for pool heating in Manitoba is about 50% of what it would be if no solar blanket were used, or about 80,000 MWh ($275 \times 10^9$ Btu) per year.

Although solar blankets are widely used on small residential pools, they are very seldom used on municipal pools, largely because of the problem of handling the large blankets required. However, some municipal pools do use them, usually with storage on a roller.

### Indoor Pools

There are about 65 institutional indoor pools in Manitoba, of which about 35 are municipally operated. If their average area is

estimated at 280 $m^2$ (3,000 $ft^2$), then the annual energy consumption of these pools will be 28,700 MWh ($10^{11}$ Btu). None use pool covers, although a pool cover probably saves more energy per year on an indoor pool than on an outdoor pool, because of the longer season and because it reduces the dehumidification load as well as the pool heating load.

## 7.4 APPLICATIONS TO DATE IN MANITOBA

The Canadian solar industry reported 9,000 plastic collectors shipped in 1979, sufficient for about 1,200 systems. Discounting this for recalls and unsold inventory, it appears that about 800 new solar pool heating systems were installed in Canada in 1979, about 10% of all pool heater sales. It is estimated that about 1,200 solar pool heaters were installed prior to 1979, and 1,200 solar heater installations are projected for 1980.

If these figures are assumed to apply to Manitoba, this means that there are a total of about 75 solar swimming pool heating systems in Manitoba at the end of 1980. This estimate is consistent with information obtained from Winnipeg pool installers.

## 7.5 ECONOMICS OF SOLAR POOL HEATING

### Outdoor Pools

Winnipeg installers of solar heating systems for residential outdoor pools recommend a collector area from 50% to 75% of the pool area, depending on the facing direction of the collector panels. The largest installers are charging about \$54/$m^2$ (\$5/$ft^2$) for a complete system. On a typical 48 $m^2$ pool, the solar energy system would cost about \$1,500, compared to \$900 for a gas-fired heater. The fuel cost for a gas-fired heater averages about \$150 per year if a solar blanket is used, so that the extra cost of the solar heaters is recovered in about four years.

In areas where gas is not available, electricity is the usual means of heating residential pools. Electric heaters are cheaper than gas heaters, averaging about \$600 installed, but the cost of electricity is about \$300 for an average sized pool with a solar blanket, so that solar pool heating pays off even more rapidly in rural areas.

The costs used here are for unglazed plastic collectors with very simple plumbing and controls. This type of system has not been widely used on municipal outdoor pools, and no data is available on such installations in Manitoba. However, the same economic analysis would apply if the season of use was the same as in a residential pool and if the same type of system was used.

### Indoor Pools

Two factors cause unglazed plastic solar heating systems for indoor pools to be more expensive than for outdoor pools. One is

that the collector location will usually be much farther from the pool, making the plumbing more expensive. The other is that the conventional heater is still required, so there is no saving to apply against the cost of the solar energy system.

On the other hand, the annual energy collected per unit area of collector will be higher for an indoor pool, if the collector is properly sized. This is because the solar collector system for the outdoor pool must be sized to heat the pool at the beginning and end of the season, and will therefore waste some collected energy in the middle of summer, while the indoor pool's system can be sized to just meet the midsummer load. Also, the collectors on the indoor pool may gain some heat in the spring or fall, when the outdoor pool is shut down.

It appears possible that an unglazed solar energy system on an indoor swimming pool in Manitoba, which was ideally suited for the installation, could yield a Simple Payback Period as short as six to eight years.

Reference 2 concludes that in every case the unglazed collector systems are more economic than the more efficient but more expensive glazed collector systems. It also concludes that it is not economic to add space heating or service water preheating to the pool heating systems.

It should be noted that there are usually profitable energy conservation opportunities in an indoor swimming pool, especially in the control of the air supply system. It would not be sensible to install a solar pool heating system without first evaluating and comparing its economics to other viable energy conservation alternatives.

One energy conserving device which can be profitable in an indoor pool is a pool blanket. This will sharply reduce the pool's heating requirements by eliminating evaporation when it is in place, and at the same time will reduce the energy requirements for dehumidification. Perhaps because the heating load of an indoor pool is not so obvious as that of an outdoor pool, pool blankets are almost never used indoors.

## 7.6 PROSPECTS FOR TECHNICAL DEVELOPMENT OF SWIMMING POOL HEATERS

The unglazed plastic swimming pool collector is a very simple device. It offers little opportunity for technical advance other than improvements in quality control to make leaks less common, and improvements in the resistance to ultraviolet light of the collector material. At present, collectors are sold with a five year warranty, and lifetime is estimated at seven to ten years, so increased durability will not have a major impact on the economics of installing a system. Manufacturing faults which cause leaks in the first year are not common in the products of the better manufacturers, but even so, they are expensive to repair and add to the cost of all collectors. Better manufacturing

techniques will probably reduce the selling price of these collectors slightly.

A possible technical advance in swimming pool heating is the development of a cheap plastic collector with plastic glazing. Such collectors are now available, but they are almost as expensive as metal collectors with glass covers. However, even if the cost is reduced to close to that of the unglazed collector, it will not have a significant impact on the economics of solar swimming pool heating because in this application, glazing has little effect on collector performance.

Another possible technical advance is a decrease in the surface reflectance of the plastic. Plastic collectors have reflectances between 25% and 35%, compared to glass at about 10%. One simple way of reducing reflectance is to roughen the surface, but manufacturers fear that this would increase dust buildup. If a low cost method of decreasing the reflectance of the plastic surface from 30% to 10% could be found, it would boost the performance of the collectors by 28% on a day when the air temperature was 27 C (81°F) and by even more when the air temperature was lower. Such an improvement would have a significant impact on the economic viability of solar pool heating systems.

## 7.7 CONCLUSIONS

1. Simple unglazed, plastic solar collectors are a cost effective means of supplying energy for outdoor swimming pool heating.

2. While not as economic as outdoor pools, simple, unglazed, plastic solar collectors can still provide cost effective water heating for indoor pools under proper conditions.

3. Any consideration of using solar energy for this application should include an assessment of applicable energy conservation alternatives.

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CHAPTER 8

# AGRICULTURAL AND FOREST PRODUCT APPLICATIONS

## 8.1 BACKGROUND INFORMATION

Solar energy applications in agriculture and the forest products industry, can be categorized into two broad classifications: process heat and space heating. Process heat is used for grain drying, lumber drying and in manufacturing processes requiring heat and pressure. Combustion of wood wastes provides much of the process energy in the forest products industry. Combustion of these wastes is done primarily as a method for waste disposal, with process heat being a by-product. Space heating applications in agriculture focus primarily on heating ventilation air for animal housing and in greenhouses. Space heating in poultry housing and in farrowing barns represents a significant portion of their operating costs. The high ventilation requirements in animal housing have been the object of numerous heat recovery and energy conservation studies. Fuel oil, propane and some electricity are used in meeting these space heating requirements. More recently there has been some interest shown in commercially available straw burning furnaces. These units are available for both space heating and grain drying applications. Heat recovery using air to air heat exchangers in animal housing has met with only minimal success. The high humidity, high particulate content and occurrence of corrosive elements in the exhaust air foul and frost heat exchange surfaces, clog filters and corrode and deteriorate reasonably priced system components. This reduces the effectiveness and increases maintenance costs of heat recovery equipment in animal housing.

Greenhouses in Manitoba and, indeed, in most of Canada utilize solar energy for a significant part of their light and heat requirements. This topic is dealt with in greater depth in Chapter 15.

Data on the energy consumption of process heat in the forest products industry and of process heat and space heat for farm purposes is not readily available. Its percentage of Manitoba's net energy consumption is small, estimated to be less than 1%.

## 8.2 ECONOMICS OF SOLAR ENERGY PROCESS HEATING IN THE FOREST PRODUCTS INDUSTRY

A large portion of process heat in the forest products industry is supplied by the combustion of wood wastes generated at the mill site. The necessity of waste disposal has lead to widespread use of steam generation as a by-product of the disposal process. This steam is used for process heat, to drive equipment and to generate process electricity.

The requirement for high temperature process heat and the usually excessive supply of wood waste at the mill site which must be combusted or otherwise disposed preclude the current economical use of solar process heating in the forest products industry.

In those areas of the industry where heat recovery from wood waste is not practical or available, such as in lumber drying kilns not associated with lumber mills, energy conservation and waste heat recovery will generally prove to be much more economical than solar energy.

## 8.3 ECONOMICS OF SOLAR ENERGY HEATING FOR AGRICULTURAL APPLICATIONS

The use of solar energy to preheat grain drying air may at first appear to be comparable to preheating low temperature ventilation air for some industrial applications. Although solar preheating of low temperature make-up air can be economical in some applications, grain drying in Manitoba is not one of these applications. Grain drying is done only during a very short portion of the year, generally six to ten weeks in the fall during harvest and must be completed quickly to avoid deterioration of the grain. In Manitoba, the years with the greatest grain drying requirements are usually characterized by cool cloudy atmospheric conditions. Further, October and November, the main drying months, have low monthly average rates of solar insolation. This combination of the short drying season and the usual fall climatic conditions preclude the economic use of solar assisted grain drying in the Manitoba environment.

Preheating ventilation air for animal housing on the other hand, may currently be marginally economical in some applications. These applications are directly comparable to those outlined in Chapter 6, Ventilation Air Preheating. Since collector inlet temperatures are essentially the outside air temperatures, low cost collectors can operate at high efficiencies (50% to 65%). Utilization of south-facing walls glazed with a fibreglass greenhouse covering results in a low cost collector which can be owner-installed at a materials costs of approximately $\$25/m^2$. Although this reduces the radiation incident on the collectors by about 10% over the heating season, relative to collectors at the optimum tilt, structural changes and costs are eliminated. If ventilation air inlet louvres are located on the south building wall, major ducting system modifications will not be required to incorporate the solar collectors into the existing system. The estimated annual energy savings are 380 kWh ($1.3 \times 10^6$ Btu)/$m^2$ of collector surface. At current oil, propane and electrical prices, annual savings would be worth approximately $\$10/m^2$ per year.

The system described would have a Simple Payback Period of three years, not including labour costs, and an expected system life of 10 years. Labour costs associated with the installation, materials cost, maintenance costs, system life, alternate fuel costs and interest rates can drastically affect the current economics of these installations.

## 8.4 FUTURE PROSPECTS OF SOLAR UTILIZATION IN THE FOREST PRODUCTS INDUSTRY

Utilization of heat generated by wood waste disposal will continue to increase in the future. As the forest products industry continues to find more profitable uses for wood wastes, there may be some reductions in the amount of wood wastes available. Advanced energy conservation

techniques will be instrumental in reducing energy consumption in this industry as it will in others. It is anticipated, that in most industry applications, conservation and heat recovery will represent a more favourable use of resources than will solar process heating.

## 8.5 FUTURE PROSPECTS OF SOLAR UTILIZATION FOR AGRICULTURAL APPLICATIONS

The short grain drying season and fall climatic conditions will continue to make solar assisted high speed grain drying uneconomical on the Canadian Prairies. The use of low cost solar collectors to preheat the inlet air for winter grain aeration systems, which remove small amounts of moisture from nearly dry grain, is also unlikely to prove economical. The solar collector, by warming the inlet air, would reduce the required aeration time. As the main purpose of aeration is maintenance of the grain at homogeneous conditions throughout the bin, significant reductions in fan operation are unlikely.

Ventilation air solar preheat on animal housing currently appears economical in some instances. Attempts at heat recovery from the exhaust air streams are now in the experimental stage and this may prove to be an alternative to solar preheating. However, should successful heat recovery equipment be introduced into the animal housing market, solar preheat may be utilized as a complimentary system on the fresh ventilation air. The low financial outlays required for owner-installed solar preheated ventilation air systems, which are integrated into south-facing exterior walls will make them favourable investments in the future.

The future economics of solar preheating ventilation air for animal housing will continue to heavily depend on system first costs, maintenance costs, system life, the cost of money (i.e. interest rates) and the cost of alternate fuels. The economics are expected to improve in the future as energy costs continue to rise at a faster rate than materials. The simplicity of the system indicates maintenance costs will be low.

Incorporating solar preheating into new structures will be more favourable than retrofitting older structures.

## 8.6 CONCLUSIONS

1. In the forest products industry, energy conservation and wood waste derived fuels are virtually always more economically and technically attractive energy saving options than active solar.

2. Post harvest solar assisted grain drying in the Manitoba climate is not economically feasible.

3. Preheating ventilation air for animal housing may currently be marginally economical in some applications. The fact that heat recovery from exhaust air from animal housing has yet to meet with significant technical or economic success increases the attractiveness of solar utilization in this use.

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# CHAPTER 9

## SOLAR COOLING

### 9.1 BACKGROUND INFORMATION

The use of active thermal solar energy to provide cooling has received very little interest in Canada, with good reason. The most common type of solar cooling equipment found in the United States uses a lithium-bromide absorption refrigeration cycle. This is a rather complex and expensive system which uses solar heated water to provide energy for cooling. Unfortunately, the collectors must heat the water to relatively high temperatures (71°-99°C) for the unit to work. Even under these conditions, it will only function with a Coefficient Of Performance of approximately 0.7 (in comparison, the COP of a conventional vapor compression cycle air conditioner is normally between 2 and 4). This means that not only do the collectors have to function at high temperature (and hence, low efficiency) but 30% of the energy they do collect can never be utilized. From a technical point of view therefore, solar cooling has some major objections.

The other problem is that the cooling loads experienced by buildings in Manitoba are usually of short duration. The cooling season for most structures consists of only July and August (less in the north). Even in the United States, with its much warmer climate, only 2% of all solar collector production in 1979 was destined for cooling applications. There are no known active solar cooling systems in Manitoba.

### 9.2 ECONOMICS OF SOLAR COOLING

Referring once again to Table 4.1 of Chapter 4, it is obvious that cooling is a very poor application for solar energy in Manitoba. The collector fluid inlet and load temperatures are high, the load is of very short duration on an annual basis and collector mounting would have to be at an angle of approximately 35° for southern Manitoba.

System costs are extremely high. One commercially available system capable of providing 3 tons of cooling capacity, which is sufficient for an average house, retails for approximately $16,000 installed. Assuming one month of continuous operation at the residential electrical rate, the Simple Payback Period (SPP) would be approximately 850 years. Another 1.3 ton system was costed and found to have an SPP of 1840 years.

### 9.3 CONCLUSIONS

1. Because of system complexities and the very short annual utilization, it is extremely doubtful that active thermal solar cooling systems could become economic in Manitoba in the foreseeable future. As well, numerous conservation strategies for cooling exist at much lower cost.

# CHAPTER 10

## PHOTOVOLTAICS

### 10.1 BACKGROUND INFORMATION

Interest in photovoltaics has grown at an unprecedented rate in the last 10 years. It is generally accepted that the long-term potential for using this technology is immense if only the current problems of cost and efficiency can be overcome.

Solar cells are semiconductor devices capable of converting solar radiation directly into electricity. Their operating efficiency is typically in the range of 10% to 15% using current production methods. Generally the installed costs are high, presently running at about $10,000 to $15,000 per peak kilowatt installed.

While this is hardly encouraging, many informed sources foresee dramatic order-of-magnitude price reductions for solar cells, similar to those experienced by other solid-state electronic devices. Certainly this is possible, but it is prudent to temper such predictions with a careful analysis of some less obvious facts. First, the tremendous price reductions experienced by many semiconductor components has occurred by progressively being able to pack more functions onto a single chip, thereby increasing its component density, thus requiring smaller areas of the expensive raw material, silicon. Solar cells, on the other hand, must cover extremely large areas if significant amounts of power are to be produced. Therefore, trying to draw a direct analogy between those two applications is not strictly accurate. A second factor concerns the anticipated price reductions due to mass production of solar cells. As was shown for thermal solar systems, much of the required technology is already well understood and dispersed within the industry. While a massively increased market would lower solar cell prices, it must be remembered that many of the necessary production processes are already employed by numerous manufacturers of other solid-state devices. Finally, while significant price reductions will certainly occur for the actual solar cells, the cost of ancillary equipment such as mounting structures, electrical conversion units and transmission systems will not be significantly altered.

These factors should not be misconstrued as a condemnation of photovoltaics, but rather as a warning of some of the potential pitfalls. In fact, the past five years have seen dramatic price reductions and the possibility of using less energy-intensive production processes with lower cost base materials will certainly result in a continuation of this trend.

Current Canadian activities in photovoltaics have been basically confined to research with only a handful of actual installations. Current R&D funding by the Federal Government is averaging near $1,150,000 per year, and is growing.

## 10.2 ECONOMICS OF PHOTOVOLTAICS

The current economics of photovoltaics is extremely poor, thereby confining their use almost exclusively to providing energy for low power applications in very remote locations.

The long-term potential, however, is probably the most difficult of all the solar technologies to comment upon. Many studies do predict significant price reductions and hence market penetration by solar cells. The United States Department of Energy, for example, has set a goal of $500 per peak kilowatt by 1986. Turn-of-the-century costs have been predicted as low as $100/kW.

For the purposes of this report, no statements beyond these are necessary due to the centralized nature of the technology. If and when their use becomes attractive, Manitobans can employ them.

## 10.3 CONCLUSIONS

1. The costs of photovoltaics conversion of direct solar radiation into electricity is currently extremely high.

2. The possibility of major price reduction within the foreseeable future using new technology exists.

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## PART II

## PASSIVE SOLAR ENERGY

Various techniques have been developed to passively utilize the sun's radiation, but virtually all incorporate the window or some other form of glazing as the central component. Every window which has access to the sun and separates heated and unheated spaces can be regarded as a passive solar collector. The energy transfer mechanisms at work in windows are surprisingly complex. Space heat is transferred through the glazing using a combined conduction/convection/radiation process with additional losses resulting from air leakage. During the day, incident solar radiation passes largely unimpeded through the glazing. Efficient passive design attempts to maximize the desired solar gains while minimizing the attendant heat losses, particularly those which occur at night. Since the energy collection, storage, and utilization functions are all generally performed without mechanical assistance, passive systems must be incorporated as an integral component of the overall building design. Therefore, the greatest potential for passive solar energy is in new construction. Retrofit projects tend to be more expensive.

It should be noted that "passive solar energy" refers solely to those building components expressly included in the structure to capture, store and utilize the incident radiation for heat or light. It does not include insulation, anti-air infiltration measures, heat recovery systems, or any other energy conservation measure.

To clarify the assessment, passive applications were divided into the following five categories:

1. Single Family Housing,
2. Multifamily Housing,
3. Commercial Buildings,
4. Warehouses,
5. Greenhouses.

CHAPTER 11

# SINGLE FAMILY HOUSING PASSIVE APPLICATIONS

## 11.1 BACKGROUND INFORMATION

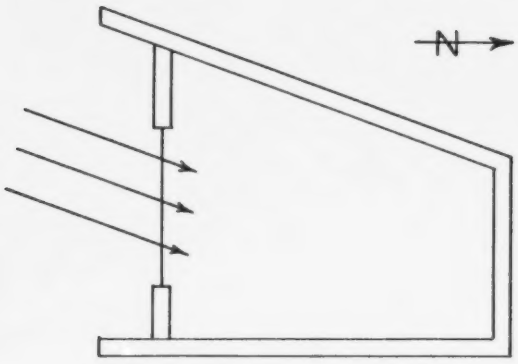
It has been estimated that approximately 0.3% of Canada's total energy consumption, for all purposes, is met by passive solar gains through windows (Ref. 1). In conventionally insulated houses, solar gains will supply 2% to 10% of the structure's true heating load as well as offering visual and aesthetic benefits. For example, an unshaded south-facing triple-glazed window, one square metre in area, installed on a typical house in Winnipeg will supply a net surplus of approximately 140 kWh worth of heating energy over the winter (Ref. 2). In an electrically heated house, this would have a value of $\$3.50/m^2$. Houses which are more energy efficient, such as those constructed to high conservation standards, will have larger fractions of their total space heating load met by passive gains, typically around 25%.

## 11.2 APPLICABLE SOLAR ENERGY SYSTEMS

Although a number of different residential passive heating systems have been developed, there are only really two potentially appropriate to the Manitoba climate. These can be generally defined as direct gain and indirect gain systems and are illustrated in Figure 11.1. (Note that attached greenhouses are discussed in Chapter 15.) A direct gain system, of which an ordinary south-facing window is the classic example, admits solar radiation and immediately uses most of it for raising the temperature of the heated space. No formal provision is made for storing some of this energy beyond that provided by the inherent mass of the structure. If the glazed area is excessively large, winter overheating of the space may result. Summer overheating is usually prevented by external overhangs (which shade the high summer sun but not the low winter sun) louvres, or vegetation. Direct gain systems can be regarded as zero cost measures if no additional glazed area is added to the house and the planned window area is simply concentrated towards the south.

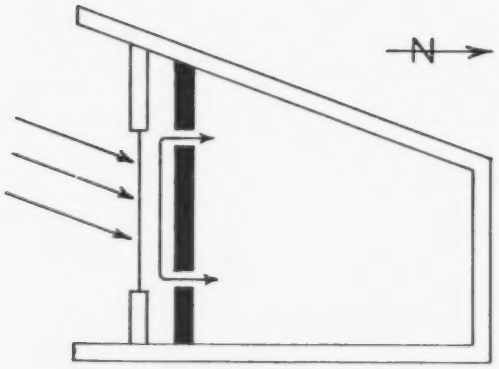
Indirect gain systems attempt to provide a thermal mass directly behind the glazing to moderate temperature swings. This mass is usually masonry, as in a Trombe wall, or water. To make significant contributions to the total heating load, large glazed areas are required. This can result in excessive nighttime heat losses if no steps are taken to increase the thermal resistance of the glazing.

Table 11.1 shows the percentage of the heating load which would be supplied by a Trombe wall and a water wall, each with and without night insulation installed on a typical house in Winnipeg. Notice that to attain a significant solar fraction, night insulation is a prerequisite.




DIRECT GAIN

Direct Gain passive solar energy systems concentrate most of the building's glazed area on the south side to facilitate collection of the incident radiation. Except for the inherent mass of the structure, no provision is made for thermal storage. Therefore, the glazed area must be carefully sized to prevent overheating of the room air.




INDIRECT GAIN

Indirect Gain passive solar energy systems also concentrate most of the building's glazed area on the south side but attempt to provide extra storage capacity and moderate temperature fluctuations by placing a masonry or water wall directly behind the glazing. To work efficienctly in the Manitoba climate, some means of reducing night-time heat losses is required.

DIRECT & INDIRECT GAIN
PASSIVE SOLAR ENERGY SYSTEMS

FIGURE 11.1

TABLE 11.1

SOLAR FRACTIONS ATTAINABLE FROM INDIRECT GAIN PASSIVE SOLAR ENERGY SYSTEMS ON A TYPICAL HOUSE IN WINNIPEG

| Type Of System | Solar Fraction | |
|---|---|---|
| | Glazed Area | |
| | 10 $m^2$ | 20 $m^2$ |
| Trombe Wall | 15% | 24% |
| Trombe Wall With Night Insulation | 25% | 39% |
| Water Wall | 13% | 19% |
| Water Wall With Night Insulation | 24% | 39% |

NOTE: For a typical house with a heating requirement of 3.4 kWh/ celsius degree days.

(Ref. 3)

## 11.3 THE EFFICIENT USE OF PASSIVE SOLAR ENERGY IN SINGLE FAMILY HOUSING

The efficient use of passive solar energy requires good design practices and quality glazing systems. Some of the components of good design include:

- the concentration of planned glazing area on a southerly exposure,
- provision of means to prevent summer overheating,
- provision of as much thermal storage mass as possible,
- provision of a means of distributing solar gains throughout the house.

Some of the characteristics of a quality glazing system are:

- high thermal resistance,
- low air leakage,
- durability and low cost,
- provision of a means of minimizing nighttime heat loss.

With the exception of the last item, all these characteristics are currently available in many commercial glazing systems. However, there is considerable variance between different window designs, particularly with respect to air leakage. For example, the leakage through a slider or awning window is typically over five times that of a casement. Proper selection is therefore of extreme importance.

## 11.4 FUTURE PROSPECTS

Passive solar energy using direct gain is, of course, already extensively used within Manitoba. The opportunity for increasing the benefits is contingent upon a number of factors.

First, a better understanding of the proper use of passive solar energy must be acquired. Fortunately, this process is already underway among both private and commercial builders. Second, better quality glazing systems are required. More airtight windows with higher thermal resistances need to be developed. Work in this area is progressing within the Manitoba window industry. Aside from general design improvements, there are three known possible technologies which could produce significant advances; the development of cost effective insulated shutters, heat-reflecting films, and external plastic glazing systems.

Insulated shutters significantly reduce the nighttime heat loss. Unfortunately, current designs are not cost effective, nor of proven durability in the Manitoba climate. Existing shutters normally retail at over $\$100/m^2$ and have Simple Payback Periods (SPP) of over 20 years,

which is likely excessively high for most homeowners. The introduction of a workable shutter onto the marketplace with an SPP of under 10 years would meet with growing commercial acceptance in the years to come.

Heat-reflecting films are another attempt at increasing the thermal resistance of glazing. These utilize one or two layers of a thin, plastic film between the two lights of a sealed, glass unit to form a quadruple-glazed window. The films are largely transparent to solar radiation but are treated to optically reflect thermal radiation back into the room. The thermal resistance is improved without major increases in weight or cost. Heat-reflecting films have been under development by a number of American firms and are now becoming available to the window industry. Their performance in our climate will still have to be evaluated although it is unlikely that major problems will be encountered (Ref. 4).

Plastic films, such as composite polymerics, are also proving to be of value as externally mounted storm windows (Ref. 5). These are generally very low in cost, lightweight, and aesthetically unobtrusive (in contrast to the oft used polyethylene). External plastic glazings have only recently been introduced in the United States and have not, as far as known, been extensively tried in Canada.

In rural settings, solar access is not generally a major problem. However, in an urban environment with high housing densities, it is difficult to provide full access to the sun for all structures unless the subdivision has been laid out specifically for this purpose.

## 11.5 THE ECONOMICS OF PASSIVE SOLAR ENERGY IN SINGLE FAMILY HOUSING

Direct gain systems which do not increase the overall glazed area of the house are virtually zero cost applications of solar energy and thus, economic. However, if the window area is specifically increased for the purpose of increasing solar gains, the economics start to deteriorate due to the additional cost of glazing. A unit area of glazing costs 50% to 300% more than an equivalent area of finished frame wall construction.

The economics of indirect gain systems are considerably poorer. Extra costs for the added glazing area, the masonry or water wall plus possible changes to increase the capacity of the foundation, all have to be considered. Referring to Table 11.1, it is also obvious that night insulation will be required if a significant solar fraction is to be attained. All these factors will result in Simple Payback Periods well in excess of 20 years. This would not likely be considered economic by most consumers. Since the added costs are largely for standard building materials, this situation is not likely to change within the immediate future.

## 11.6 CONCLUSIONS

1. The proper use of direct gain passive solar energy is an integral component of good house design and can usually be incor-

porated at zero cost at the design stage. Measures such as the proper location of glazing, the use of low leakage windows with high thermal resistance and the provision for summer shading should all be considered at the design stage.

2. Due to the inherently higher costs of indirect gain systems, they are not now economic in Manitoba, nor are they expected to become so within the immediate future, based upon present technologies and economics.

3. The most significant improvements in the use of passive solar energy for single family housing will be through its better utilization by designers plus the introduction of improved glazing components and systems. Products such as low cost insulated shutters, heat-reflecting films and plastic glazings would be extremely useful and could potentially reach the market in the near future.

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(SINGLE FAMILY HOUSING)

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CHAPTER 12

# MULTIFAMILY HOUSING
# PASSIVE APPLICATIONS

## 12.1 BACKGROUND INFORMATION

Multifamily housing encompasses dwelling units ranging in size from small walk-ups to high-rise apartments. The characteristics of using passive solar energy for this application are similar to those for single family housing except the heat loss per unit floor area is generally lower due to the higher ratio of building volume to exterior surface area.

## 12.2 APPLICABLE SOLAR ENERGY SYSTEMS

Once again, the only two types of passive solar energy systems which are potentially appropriate to multifamily housing in Manitoba are direct and indirect gain systems. For a discussion of these, the reader is referred to Chapter 11.

## 12.3 THE EFFICIENT USE OF PASSIVE SOLAR ENERGY IN MULTIFAMILY HOUSING

The same basic principles which applied to single family housing also apply here, especially the problem of overheating. Since the heating load per unit floor area is lower in larger structures, the passive solar gains become more pronounced. Therefore, designers must take special care to ensure that glazed area which has been relocated to a southerly exposure does not unduly contribute to the air conditioning load. Unfortunately this can often be an expensive and difficult task unless design aids, such as computer simulation programs are available at a reasonable cost. Suitable programs are now starting to become available.

## 12.4 FUTURE PROSPECTS

A better understanding of passive solar energy in multifamily housing design, coupled with the appropriate design tools and improved glazing systems, should all lead to its increased utilization within the next few years. For more details, see Section 11.4.

## 12.5 THE ECONOMICS OF PASSIVE SOLAR ENERGY IN MULTIFAMILY HOUSING

The only major difference from single family housing is the possibility of increased cooling loads. This is particularly important since the cost of providing cooling energy is higher than the cost of heating energy. Whether the trade-off between lowered heating costs for potentially increased cooling costs is justified is a question which has to be answered for each project. This accents the need for better design tools.

In general, direct gain systems would prove to be economic and indirect gain systems, uneconomic. However, clever design can often increase the effective storage mass by repositioning required walls, columns or other structural members to better "see" the sun.

## 12.6 CONCLUSIONS

1. The proper use of direct gain passive solar energy is an integral component of good multifamily housing design and can often be incorporated at zero or low cost at the design stage. Measures such as the proper location of glazing, the use of low leakage windows with high thermal resistance and provision to control overheating of the space should all be considered at the design stage.

2. Due to the inherently higher costs of indirect gain systems, it is unlikely that they will become economic within the immediate future, based on present technology and economics.

3. The most significant improvements in the use of passive solar energy for multifamily housing will be through its better utilization by designers, the existence of new design tools, and the introduction of improved glazing systems and components. Products such as low cost insulated shutters, heat-reflecting films, and plastic glazings would be extremely useful and could reach the market in the near future.

CHAPTER 13

# COMMERCIAL BUILDINGS PASSIVE APPLICATIONS

## 13.1 BACKGROUND INFORMATION

The primary focus of most solar applications is the production of energy for heating purposes. In residential structures, for example, approximately two-thirds of the total energy costs are for space and water heating.

In contrast, commercial buildings have much smaller heating loads per amount of floor area due to the inherent heating efficiency of large structures. If the building's heat and ventilation systems have been properly designed to minimize the energy wasted for control purposes, electric lighting will generally become the largest single component of the energy bill, typically amounting for 25% to 50% of the total cost.

## 13.2 APPROPRIATE USES OF PASSIVE SOLAR ENERGY IN COMMERCIAL BUILDINGS

As discussed earlier, space and water heating loads in commercial buildings are extremely expensive to meet using active solar energy-systems. Passive solar energy can be used to produce reductions in the heating load if the proper design principles are followed. However, potential overheating problems usually limit its applicability to small and medium sized structures. For a more detailed discussion of passive solar heating in these sized buildings, refer to Chapters 11 and 12.

Any source of light produces heat as a byproduct. In small structures with significant heating loads, this "waste" energy can be used to reduce the fuel bill. In large structures, such as commercial buildings, it can create an overheating problem in all but the coldest periods of the winter. This increases cooling loads and costs since not only is extra electricity consumed, but the building's peak electrical demand is also increased. Good commercial lighting design attempts to increase the production of light and minimize the waste heat given off, i.e. maximize the lumens per watt ratio.

Artificial lighting systems generally have low lumen/watt ratios, typically 20% to 50% of those produced using natural daylight. By using "daylighting", electrical consumption and demand as well as the cooling load can be reduced. Also, most people have a marked preference for natural lighting, thereby producing possible side benefits such as increased worker productivity.

Daylighting basically consists of modifying the building design by adjusting a number of architectural variables in such a manner that larger than normal fractions of the lighting load can be met by solar radiation. This requires redesign and redistribution of the glazing system, especially to increase natural lighting levels in interior zones. Obviously, this is most appropriate to new construction.

Since provision must be made for full supplemental lighting when sufficient sunlight is not available, a complete artificial lighting system will still be required. A control system, either manual or automatic is used to dim or shut off the electric lighting whenever daylighting can meet all or a portion of the load. Most existing control and lighting sytems are not very appropriate for integration with daylighting schemes; however this area is the subject of a great deal of activity within the lighting industry. Improved products should become available in the near future.

## 13.3 ECONOMICS OF DAYLIGHTING IN COMMERCIAL BUILDINGS

Very little reliable information on daylighting costs is available since it is generally difficult to isolate the incremental cost of resulting from the partial redesign of a structure. It would appear that if daylighting is incorporated at the design stage, it can often be economically justified in many larger commercial structures. However, the total savings are likely to represent only a small percentage of the total lighting budget. As more design experience is gained and higher quality glazing (see Chapter 11) and lighting control systems become available, the economical use of daylighting will increase.

## 13.4 CONCLUSIONS

1. The most appropriate and economic use of passive solar energy in small and medium sized commercial buildings is direct gain heating systems.

2. The most appropriate and economic use of passive solar energy in large commercial buildings is daylighting - the use of natural lighting to reduce or replace artificial lighting.

3. The use of daylighting in large commercial buildings will increase as more experience is gained and improved lighting control and glazing systems become available.

CHAPTER 14

# WAREHOUSES
# PASSIVE APPLICATIONS

## 14.1 BACKGROUND INFORMATION

For the purposes of this report, warehouses will be defined as buildings with extremely low human occupancy rates, minimal internal heat gains and minimal fresh air requirements. The spaces may be unconditioned, heated only, cooled only, or fully air conditioned, as dictated by the use of the warehouse. Only those buildings requiring heating are of interest to this report.

## 14.2 ECONOMICS OF WAREHOUSE HEATING USING PASSIVE SOLAR ENERGY

As with most other active solar applications, solar space heating in warehouses, which do not have significant fresh air requirements, is not economically feasible. The opportunity for economically utilizing cost effective passive solar energy conservation techniques does exist in both new and retrofitted warehouses, with new construction presenting the greatest opportunity for innovation. In all structures, it is imperative that energy conserving features not interfere with the function of the structure. They must not adversely affect the useable space, the accessibility or the required physical environment of a warehouse. The variance in their use means that a single set of design criteria cannot be universally applied to warehouses, but rather that each application be considered on its own merits.

Passive solar opportunities in warehouses include varying location, orientation, shape, and using insulation, glazing and the thermal mass of the structure and its contents. If the opportunity exists to pick the location, orientation, and shape of a warehouse, these should be selected to minimize the building heating and/or cooling load. Frequently the shape of a warehouse is restricted in that the entire structure must be on one level, due to the high floor load requirements, or because the amount of cargo traffic makes multiple level structures impractical. Frequently building location and orientation are predetermined by other site or operational limitations. In existing structures, these features cannot be changed.

The use of insulation, glazing and the thermal mass in a warehouse for temperature stabilization are less restricted passive solar options. Insulation levels in new structures can be cheaply increased to meet the economically optimized thermal resistance level for its operating temperature. Insulation can be viewed as a zero maintenance building component with a life equal to that of the structure in most cases. The economic justification for reinsulating existing structures is dependent largely on the existing insulation levels, and the operating temperatures in the structure. Poorly insulated buildings operating at high temperatures (say 20°C as opposed to 0°C) can easily justify retrofitting whereas in better insulated buildings, or in those operating at low temperature, the energy savings may not justify the cost.

Glazing and the use of the thermal mass of the warehouse and its contents for passive heating may offer significant energy savings in some structures. The solar gains of a south-facing double- or triple-glazed window will exceed the heat losses through them in most Manitoba locations, depending on the amount of infiltration around the window frames. The value of these incremental solar gains are dependent upon the system's ability to utilize the heat transmitted by the glass. This is a function of the size and nature of the heating season, the heating requirements of the warehouse, and the ability to store and utilize the solar gains when they exceed the immediate heating demands.

As the amount of glazing on a structure increases the absolute value of the solar contribution increases while the ratio of solar utilized to solar available will decrease. The size of the thermal storage is very significant in this relationship. Decreasing thermal storage increases the frequency that excess solar gains must be dumped. As the glass area on the south wall is increased, the incremental value of useful solar gains decreases. Beyond a certain point, a further increase in the glazing area will result in an actual increase in the auxiliary fuel requirements in the structure. This occurs because the heat losses of windows greatly exceed those of the insulated wall sections that the windows replace. The incremental heat losses of additional windows are constant, while the incremental useful solar gains decrease until their value is actually less than the additional heat losses incurred. As noted, the thermal storage capacity of the structure, and its heat loss rate have a major influence on the solar fraction in a passive solar heated warehouse.

The thermal mass of a warehouse and its contents may not be significant thermal storage. Warehouses tend to be empty buildings with the concrete floors offering the only significant building mass, and concrete floors do not easily or quickly absorb heat from room air. Incident solar radiation is more readily absorbed, but storing it in floors requires that this floor space not be used for materials storage. The housed goods may offer a huge thermal mass, but generally these goods are only temporarily stored in the warehouse, so they cannot be considered for long-term storage. Having solar radiation incident upon some housed goods may be unacceptable. The packaging of some goods may impede the transfer of heat into and out of the goods, or reduce air circulation, which could neccessitate forced ventilation through the goods to facilitate the process of thermal storage.

Aside from the points discussed, probably cost and security are the two drawbacks which will most negatively impact the widespread use of passive solar space heating in warehouses. The first cost of an air-tight double- or triple-glazed window will typically be several times more than an equal area of warehouse wall. Maintenance costs on glass can be high if weather seals deteriorate or if the windows are subject to breakage (due to birds, vandalism, accidents or structural shifting which may occur if the building is unheated through a winter). Also, large glass areas make the building more susceptible to theft during unoccupied hours.

Trombe walls have even greater first costs than glass walls. Their high mass may necessitate use of special footings, the cost of the wall and any controls incorporated into it will exceed the costs of a standard wall, while the glazing for the wall will be at least as expensive as a normal window. Trombe walls may have lower thermal losses (thus a greater net energy gain) than conventional windows, but they do not facilitate natural lighting and cannot be otherwise used as windows.

From a purely economic standpoint, it is questionable whether south windows or Trombe walls will be justifiable in the foreseeable future in warehouses. An investment similar in magnitude (to the cost of a Trombe wall or extensive glazing) in energy conservation features over the entire structure would, in most cases, result in a greater reduction in the auxiliary fuel consumption of the structure. These features may include increased insulation levels, circulation fans to prevent warm air stagnation in ceiling spaces, local radiant heating instead of space heating, vestibules, traffic curtains, air doors, enclosed loading ramps, etc. Any glazing in the structure will be most beneficial, from a heating standpoint, if it is located on an unshaded south exposure. In cooling applications, glazing should be avoided or located in a north or shaded wall area.

## 14.3 CONCLUSIONS

1. Zero or low cost passive solar modifications to warehouses, such as orientation and building shape optimization may be currently justified in new construction. However, elaborate passive features cannot compete with conventional fuels or energy conservation alternatives on an economic basis.

CHAPTER 15

# GREENHOUSES

## 15.1 BACKGROUND INFORMATION

The greenhouse industry in Manitoba is currently a small scale industry which meets part of the province's demand for flowers, potted plants and bedding plants. Winter production of vegetables on a commercial scale has been virtually eliminated due to high operating costs. It is estimated that there are 15 acres of greenhouse in Manitoba (Ref. 1) of which 8 to 10 acres are operated year-round, representing less than 1% of Canada's greenhouse area (Ref. 2). As a result, most greenhouse products sold in Manitoba are imported for direct sale or for finishing before sale. Reductions in greenhouse operating costs, of which energy and labour represent 80% (Ref. 1), could make the local industry competitive in some product areas. Energy costs for Manitoba greenhouses were estimated at $80,000 to $107,500/hectare/year in 1979 (Ref. 1,4). An industry growth from the current $3 million level to the Canadian average of $15 million or more is conceivable because despite its severe winter climate, Manitoba enjoys an abundance of winter solar radiation.

As in most other industries, the rapid price escalation in the cost of conventional fuels has stimulated research into the application of alternate energy sources and energy conservation techniques for greenhouses. Solar energy researchers have coined the phrase "solar greenhouse" which can be a source of some confusion. All greenhouses are, by definition, "solar" in that the sun is used to trigger the photosynthesis reaction and supply some of the heating energy. What has colloquially become known as a "solar greenhouse" is a small hobby greenhouse which provides some part of the fresh produce for a normal-sized family. Excess heat from the greenhouse may be used to meet part of an external space heating load. This type of addition to residential structures may be aesthetically pleasing, but in Manitoba at least, they should not be viewed as energy saving devices. Proper design and construction of these structures will maximize their benefits while minimizing their energy consumption, possibly even eliminating their net annual energy consumption. At present solar greenhouses have an insignificant impact on the province's energy consumption and its economy because of their small size and numbers. However, the "solar" greenhouse industry, which is now experiencing a popularity boom, should not be ignored.

## 15.2 APPLICABLE SOLAR ENERGY SYSTEMS

Both active and passive solar designs have been reviewed for commercial greenhouse applications. Aside from these, numerous energy conservation techniques are being researched and developed. When one considers use of energy alternatives in greenhouses, it must be remembered that the purpose of the greenhouse is to grow plants. Any device or procedure which disrupts the growing environment and reduces production, proportionally increases all costs relative to output from that greenhouse. Procedures which increase labour requirements must be compared economically with the benefits (energy savings and/or increased output) they generate. Further, practices which disturb the timeliness of greenhouses

cannot be tolerated. Poinsettas are worth very little after Christmas, Easter lillies lose their value after Easter, and rose sales may drop drastically after Valentine's Day and Mother's Day. The two basic ways of decreasing the relative operating costs for a greenhouse are to reduce the energy consumption of the structure without impacting on output, or to increases output from a given greenhouse, while maintaining energy costs. As the second alternative may reduce other costs (capital costs, maintenance costs, labour costs, etc.) relative to output, it has a potentially greater economic impact on the industry.

As with other active solar applications, capital cost is one of the major obstacles to the economic use of active solar energy systems in greenhouses. To provide a reasonable fraction of solar heating (e.g. one-half) it is estimated that one unit to one and one-half units of external collectors are required per unit of heated greenhouse floor area and the lower solar altitude in the winter means one unit of collectors requires two or more units of land to avoid shading (Refs. 2,3,4,5). The current cost of commercial solar collector installations greatly exceeds the cost of greenhouse construction (which ranges from $300 to $1,000/m$^2$). This high capital cost, plus the large land requirements of the collector area do not compare favourably to similar expenditures on energy conservation alternatives or techniques to increase crop densities.

Active systems which use the greenhouse as the collector have lower capital costs and no specific land requirement, but they impose severe limits on the maximum possible collection temperatures. This in turn restricts the temperature range through which the thermal storage can cycle, resulting in a need for extremely large thermal storage. As well, solar equipment located on the roof or in the ceiling space of the greenhouse may interfere with solar intensity and distribution in the greenhouse, adversely affecting crop production.

It is difficult to draw fine distinctions as to whether many greenhouse features are energy conservation measures or passive solar considerations. This report will not debate the issue, but will consider each of these measures on its own merits.

Passive solar greenhouse design attempts to make the greenhouse a good solar collector and thermal storage system during the day, and an energy efficient structure at night. Considerations that may be viewed as passive solar design elements are greenhouse location, orientation, shape, size, wall and roof construction, utilization of moveable insulation or night covers, operating temperature regimes, and utilization of inhouse thermal storage.

The significance of greenhouse location, orientation, and shape, is very dependent on greenhouse size. As the size of the greenhouse increases, exterior walls become a smaller percentage of the total glazed area, as long as the ratio of greenhouse length to width remains small. As the fraction of glazed area along the perimeter of the greenhouse is reduced, its location and orientation become less significant. Heat losses and solar gains become almost directly proportional to roof area in large greenhouses. Although these factors may have considerable

impact on the energy costs in small greenhouses, location, orientation and shape (except for the shape of the roof) are not major considerations in large commercial structures. Computer models exist which can be used to define optimum orientation and shapes for smaller houses.

Energy losses from greenhouses are primarily skin and infiltration losses. These are largely a function of the wall and roof areas and their construction. In Manitoba, the standard commercial greenhouse equipped for winter operation is a double-walled structure, with fibreglass outer and polyethylene inner walls and roof. The integrity of the polyethylene and the method by which it is fastened will have a significant impact on the infiltration rate. Addition of more transparent layers should decrease losses, but will at the same time, reduce the solar transmissivity of the surface. This loss of solar transmissivity reduces crop yields and solar heat gains. Excessive reductions in air infiltration results in depletion of carbon dioxide ($CO_2$) from the house atmosphere and excessive humidity buildups, necessitating forced ventilation or $CO_2$ enrichment in the greenhouse if plant growth is to be maintained. Excessive reductions in heat loss through the roof result in snow buildup which can cause structural damage as well as obscuring the sunlight. However, insulation of north walls, the knee walls and footings is generally economically justifiable in greenhouses operated throughout the winter.

The utilization of moveable insulation or night covers permit greenhouses to be operated as energy efficient, opaque-walled structures at night, and to function as normal during the day. The Beadwall concept fills the space between the inner and outer glazing with insulation particles during the night, which greatly reduces heat losses. During the day, the insulation is removed to allow normal operation. A pneumatic transport system moves the insulation into and out of the wall cavities. Variations of this concept include the injection of an insulating foam into the wall cavity. This foam is reliquified for removal from the wall. These concepts are of particular interest to new construction. Although some operational problems exist, the Beadwall system is near commercial availability.

Nighttime heating requirements may be greatly reduced by using highly insulated thermal blankets within the greenhouse. These may be used to isolate warm areas from cool areas or to insulate exterior surfaces. Blankets or curtains insulating exterior greenhouse walls act in three ways to reduce heat losses. Reflective blanket surfaces reduce radiation from the greenhouse, increase the R value, and possibly reduce infiltration losses. Blankets can reduce night heating needs by 60% to 80% (Refs. 3,4,6) and shade the plants during periods of excess sunlight. However, they are not without their problems. Insulating curtains are expensive, there are some mechanical problems with the operating mechanisms, storage is usually in the greenhouse roof, which causes shading problems, and condensation or frost buildup can occur on the inner glazing when moist air from within the tent passes over cold glazing surfaces, which may cause shading and/or dripping on the plants (Ref. 7).

Another energy conserving technique which may qualify as passive solar is related to the greenhouse temperature regime used. If the greenhouse contains different varieties of plants or plants at various stages of development which have different temperature tolerances, they should be segregated. Each area of the greenhouse should be allowed to swing through its maximum permissible temperature range from day to night. Plants with the highest temperature requirements should be located away from outside walls, while those with the lowest permissible temperatures should be located along the outside walls. Soil heating techniques may reduce the air temperature requirements in the greenhouse. The energy savings realized from this technique will vary from crop to crop, and are directly related to reductions in the mean difference between indoor and outdoor air temperatures.

An important component in most passive solar energy designs is thermal storage. Long-term (i.e. seasonal) and short-term thermal storage systems have been investigated for both active and passive greenhouse solar applications. In the mid-east USA, greenhouses have been heated throughout the winter using salt water thermal storage ponds as the heat source (Ref. 3). Initially heat is extracted directly from the brine (using heat exchangers) but as the pond temperature drops, heat pumps are used to extract useful heat from the pond. Pond volumes considerably exceed greenhouse volumes. These systems are still in the development stages and a number of technical problems remain to be solved before they are commercially feasible (Ref. 8,9).

A study on solar heating in southern Ontario greenhouses (Ref. 4) reports that the sun can provide only about 30% of the total heat energy required for greenhouses in December, January and February, assuming that the greenhouse can utilize 100% of the incident solar energy. This is a time period in which 60% of the annual heating load occurs in southern Ontario. In Manitoba, with its lower solar incidence angles and colder climate, the solar contribution will be deficient for a longer portion of the year. This low solar contribution, which does not even meet immediate heat loads during much of the heating season, limits the usefulness of short-term thermal storage.

Long-term passive thermal storage within commercial greenhouses requires huge thermal masses because of the limited permissible temperature swings. For this reason they are impractical. Foundations must be upgraded to support the weight of storage. Under-bench thermal masses preclude the opportunity to utilize moveable planters, which permits increases in plant densities of about 33% (i.e. 60% useable bench area in conventional houses, 80% with moveable planters) over conventional bench systems.

## 15.3 FUTURE PROSPECTS

On an annual basis, the solar energy incident on a conventional greenhouse is in excess of the greenhouse heating requirements. On a seasonal basis, summer radiation greatly exceeds the heating requirements, while winter radiation levels are generally not sufficient to maintain greenhouse temperatures throughout daylight hours. For a period of about two months in the spring and fall it is conceivable to

meet heat loads in conventional greenhouses using short-term thermal storage.

In order to make solar heating more feasible in greenhouses in Manitoba, the energy consumption in greenhouses must be greatly reduced. The greenhouses must be made energy efficient to the point where passive solar gains are sufficient to maintain acceptable daytime temperatures before solar heat can economically be used, and night losses must also be controlled. Alternate storage systems which do not interfere with greenhouse operation and allow for long-term thermal storage may favourably affect the feasibility of active solar systems for greenhouse heating, but it appears unlikely that these systems will become economical.

Manitoba greenhouse operators currently meet only a small fraction of the province's out-of-season fresh plant and produce requirements. Substantial reductions in the operating costs of greenhouses, relative to their output, are required to stimulate a growth in the industry, now estimated at $3 million per year. A fivefold increase in commercial greenhouse area in the province would bring Manitoba on par with the Canadian average, on a population basis. A much larger increase in area would be necessary to displace fresh produce imported from the United States and Mexico.

The small profit margins and short time horizons associated with greenhouse operation in Manitoba make it extremely difficult for operators to research and develop or adapt new technologies for the Manitoba environment. However, for survival, the industry must develop a long-range strategy.

Long-term considerations should be the introduction of energy conserving houses which utilize alternate or waste heat sources. Exhaust gases from power plants or large industrial facilities have been investigated and in many cases, appear extremely cost effective (Ref. 10,11). Locating greenhouses on the roof of large heated buildings or using heat pumps to extract low grade heat from sanitary sewage or waste water streams may hold promise for reducing energy costs. Mines, smelters, and thermal-electric (diesel) generation stations are some potential waste heat sources in the North.

In summary, reductions in energy costs in the greenhouse industry in Manitoba will reduce energy consumption in the province, and at the same time, encourage an expansion of this industry. The result should be a reduction in the amount of direct energy consumption that Manitoba exports, and an improvement in the provincial economy.

## 15.4 CONCLUSIONS

1. Passive solar energy is marginally economic in new greenhouse construction provided it is incorporated at the design stage and the greenhouse production of crops does not suffer. However, the total savings attributable to the passive features would be moderate.

2. Passive solar energy is not economic for retrofit applications on existing greenhouses.

3. The most cost effective means of reducing energy consumption in new or existing greenhouses is through the proper use and operation of various energy conservation alternatives.

4. Any greenhouse developments which lower operating costs for Manitoba growers may similarly affect the cost of growers in other geographic locations. It cannot be assumed that these developments will necessarily make Manitoba growers more competitive in the Manitoba market, unless the magnitude of savings accrued to local growers exceed those available to outside growers.

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